A development path for small wind energy systems in South Africa

KI Olatayo
24018597

Thesis submitted for the degree *Philosophiae Doctor* in Development and Management Engineering at the Potchefstroom Campus of the North-West University

Promoter: Prof JH Wichers

May 2017

ACKNOWLEDGEMENTS

The progress and completion of this thesis were made possible through the continuous assistance, guidance, and support of several individuals and organisations.

Firstly, I would like to express very deep appreciation for my supervisors. Special thanks to Prof. PW Stoker, for his tutoring, mentoring, supervision, and leadership throughout this work. Similarly, appreciation goes to Prof. JH Wichers for his willingness, supervision, guidance, and support towards the final submission of this thesis.

Equally, I am grateful to all the participants and organisations that participated in the interviews/questionnaires and other research work processes and activities. They greatly contributed to enhance the experience and results obtained in this research study. A special appreciation is extended to the South African Weather Service.

Furthermore, this research was supported financially by a university bursary, and importantly, through the contributions of Andre Hattingh, Rudi van der Merwe, and the Innovation Office of THRIP. Thank you.

I deeply thank and dedicate this work and achievement to my special and lovely wife, Lian; our great children Pelumi and Damilare; wonderful dad and mum (Grandpa Olufemi and Grandma Bolanle Olatayo); sisters and brother (Tope, Funmi, Tosin and Wole); and in-laws (Chukwueke family – Grandpa Raymond, Grandma Sabina, Onye, Roddy, Lilian, Rose, and Augusta) for their unalloyed support in terms of love, patience, finance, counselling, encouragement, and most importantly, prayers.

Furthermore, I appreciate the Pastor Tinuoye family, Oladimejis, Ogunbunmis, Ogunlanas, Oyedejis, Falaiyes, Hamodus, Ojos, Oyenusis, Oladirans, Oladojas, Mayekisos, Pastor Romney, Bro. Stephen, Nicholson, friends, and colleagues for their prayers, encouragements, and well wishes.

Finally, my utmost gratitude belongs to my Lord and Saviour, Jesus Christ.

ABSTRACT

South Africa's electricity generation is primarily through coal, and this contributes significantly to the country's high carbon emissions. In 2010, the Department of Energy, initiated the Integrated Resource Plan (IRP) 2010–2030 as part of the government's redefinition of its energy portfolio and commitment to wind energy development. This, most recent, IRP document proposes 8.4 GW new-build installed wind capacity by 2030. While a significant percentage of this proposed capacity is expected to be generated by large scale wind turbines, the IRP document also recommends contributions and further research in off-grid technologies and activities. However, off-grid small wind technology is still at infancy in South Africa, with very little development thus far. Therefore, this sector needs to be further researched and developed, for these small wind technologies to contribute to the proposed GW.

Towards the development of the small wind sector in South Africa, two developmental variables – policy and technology performance – were examined, as key factors often responsible for the failure or underdevelopment of renewable energy projects include inconsistent government policies, poor technology and relatively poor productivity, administrative hurdles, bureaucracy, and non-transparent permitting procedures (Beck *et al.*, 2004; Gross *et al.*, 2010; Schwerin, 2010). Therefore, this research evaluated the effects of the available policies benefitting small wind systems and technology performance of these systems on the viability and future growth of the sector in the country, and proposed an alternative development path to overcome the limitations.

The policy evaluation involved comparing and analysing the effects of the support policies for small wind sectors in South Africa and the U.S and UK (developed sectors) on the growth of the sector. The results revealed the different levels of deployment in the three countries are largely influenced by the return-risk factors. While both the U.S. and UK small wind markets are considered as developed and SA still infancy, the deployment level can be categorised as high in the U.S., medium in the UK, and low in SA. The U.S and UK case studies illustrated the synergy between the return and risk factors for best results, while the low level of deployment in SA described what can be expected from a sector with absence of favourable return and risk factors, even though there is a favourable wind resource. In general, the results from the policy evaluation

established that, the viability and future growth of the small wind sector in South Africa are limited by the presently available policies benefitting the small wind energy systems.

The technology performance evaluation involved analysing the techno-economic performance (energy productivity and economic performance) of small wind energy systems in twelve different locations of South Africa, categorised into four different regions due to the variation in the wind resources of the country and the large expanse of the geographical area. In all the considered sites for the two different-rated turbine models selected for this research, the energy performance results revealed that some locations such as Port Elizabeth and Cape Town provided relatively productive performances, while others yielded poor returns on output. The economic evaluation results established that small wind energy systems are not yet economically viable in the country under the present policies and considered assumptions. Considering small wind generated electricity reduces greenhouse gas (GHG) emissions, technically, a very small amount of GHG reduction is achieved according to the relatively low energy outputs of the two turbines analysed, thus, low environmental value is added or achieved. However, the internalisation of external costs of conventional generation in the cost analysis of small wind systems in the country enables the environmental benefits of these systems to be expressed in economic terms, hence, making them fairly competitive. In conclusion, the results established that, the viability and future growth of the small wind sector in South Africa is limited by the technology performance of the systems.

Given that the viability and future growth of the small wind sector in South Africa is limited by the presently available policies benefitting the systems and technology performance, this thesis proposed an alternative development path to overcome the limitations identified. As revealed by this research study, these limitations include insufficient financial incentives; policy uncertainty; poor administrative processes; high investment costs; uncompetitive Levelised Cost of Energy (LCOE); and the absence of a plan/path towards a free competitive market and sustainable development. The proposed development path presented two growth paths, termed the advanced-growth and moderate-growth development path to overcome these limitations. The advanced-growth development path, which is incentive-driven, proposes and develops a template for granting investment capital subsidies (grants or loan) to consumers, as a near-term temporary market-pull solution to reduce high up-front costs' burden, stimulate demand

and realise quick growth of the sector in the country. The moderate-growth development path proposed and analysed a long-term solution involving learning and scale effect mechanisms, to achieve cost reduction and competitiveness of the system, commercial viability, and sustainable growth of the sector.

Keywords: small-scale, wind, energy, generation, policy, technology, performance, development path, economic, viability, sustainable, future growth.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

AAWS	Average Annual Wind Speed
AC	Alternating Current
AEP	Annual Energy Production
AGL	Above Ground Level
AWEA	American Wind Energy Association
BWEA	British Wind Energy Association
Capex	Capital Expenditure
CoCT	City of Cape Town
CSIR	Council for Scientific and Industrial Research
CSP	Concentrated Solar Power
CSS	Clear Skies Scheme
DBSA	Development Bank of Southern Africa
DC	Direct Current
DEA	Department of Environmental Affairs
DECC	Department of Energy and Climate Change
DME	Department of Minerals and Energy
DoE	South African Department of Energy
DTI	South African Department of Trade and Industry
DTI UK	Department of Trade and Industry United Kingdom
EMI	Electromagnetic Induction
ESKOM	National electricity provider
EWEA	European Wind Energy Association
FIT	Feed-in-Tariff
GEF	Global Environmental Facility
GEEF	Green Energy Efficiency Fund
GHG	Greenhouse Gas
GW	Giga Watt
GWh	Giga Watt-hour

H_1	Alternative Hypothesis
H_0	Null Hypothesis
HAWT	Horizontal Axis Wind Turbine
IC	Initial or Investment Costs
IDC	Industrial Development Corporation
IDM	Integrated Demand Management
IEA	International Energy Agency
IEC	International Electro-technical Commission
IRP	Integrated Resource Plan
ITC	Investment Tax Credit
kW	Kilo Watt
LCBP	Low Carbon Buildings Programme
LCOE	Levelised Cost of Energy
MCS	Micro-generation Certification Scheme
MW	Mega Watt
MWh	Mega Watt-hour
NEEA	National Energy Efficiency Agency
NERSA	National Energy Regulator of South Africa
NMMU	Nelson Mandela Metropolitan University
NPV	Net Present Value
OCGT	Open Cycle Gas Turbine
PPA	Purchase Power Agreement
PTC	Production Tax Credit
PV	Solar Photovoltaic
R	Rand
RBS	Revised Balanced Scenario
R&D	Research and Development
RD&D	Research Development and Deployment
RE	Renewable Energy
REIPPPP	Renewable Energy Independent Power Purchase Procurement Programme

REI4P	Renewable Energy Independent Power Purchase Procurement Programme
REFIT	Renewable Energy Feed-in Tariff
RO	Renewable Obligation
ROC	Renewable Obligation Certificate
RPS	Renewable Portfolio Standards
RSA	Republic of South Africa
SA	South Africa
SANEDI	South African National Energy Development Institute
SAPVIA	South African Photovoltaic Industry Association
SAREC	South African Renewable Energy Council
SASTELA	South African Solar Thermal Industry Association
SAWEA	South Africa Wind Energy Association
SAWEP	South African Wind Energy Programme
SAWS	South Africa Weather Service
SESSA	Sustainable Energy Society of Southern Africa
SOP	Standard Offer Program
SPP	Simple Payback Period
SWCC	Small Wind Certification Council
SWES	Small Wind Energy System
SWTDP	Small Wind Turbine Development Path
SWT	Small Wind Turbine
TWh	Tetra Watt-hour
UK	United Kingdom
UN	United Nations
U.S.	United States
U.S. DOE	United States Department of Energy
VAWT	Vertical Axis Wind Turbine
WASA	Wind Atlas for South Africa
WWEA	World Wind Energy Association
ZAR	South African Rand

CHAPTER 1
INTRODUCTION AND SCOPE OF RESEARCH

1.1 Introduction

South Africa's electricity generation is primarily through coal, a resource abundantly deposited in the country. The national electricity provider, ESKOM, generates the nation's electricity from 90% coal, 5% nuclear energy, and 5% other sources (DoE, 2011). The generation through coal contributes significantly to the country's high carbon emissions, making South Africa the 14th highest emitter of greenhouse gases (GHGs) in the world (Ayodele *et al*, 2012a). However, similar to many other countries, energy price instability, insecurity of supply, localization, climate change, and environmental pollution are concerns driving South Africa to redefine its energy portfolio and cultivate other sources of clean energy. These factors have motivated the nation to work towards generating more energy from renewable resources – resources that are free, localised, and environmental-friendly (Ayompe, 2011; Luthi, 2011; Shawon *et al*, 2013). This redefinition of the country's expected energy mix by the South African government has resulted in institutional changes recognising the benefits of renewable energy, and specifically, the potentials of wind energy, a clean, environmental friendly, technologically matured, and comparatively low cost energy source (Leung *et al*, 2012; Mostafaeipour, 2013).

A review of the research performed on South Africa's wind resources showed that several studies have been conducted to evaluate the country's wind energy potentials. These studies, including Diab's *Wind atlas of South Africa* (1995), the *Strategic study of wind energy deployment in Africa* of Helimax Energie (2004), and Hagemann's *Mesoscale wind atlas of South Africa* (2008), clarified the magnitude of the wind resources and provided more accurate information concerning it. Being a nation with a wind power generation potential estimated at 80.54 TWh, that could be realized with an installed capacity of about 30.6 GW (Edkins *et al.*, 2010), South Africa can become the continent's leading wind power producer. Furthermore, similar to many other countries, regulatory frameworks are being introduced by the government to play an important role in shaping the norms and expectations of stakeholders in the wind industry.

1.2 Problem Statement

As part of government's commitment to wind energy development in the country, the Department of Energy, through collaboration in November/December 2010, initiated a modelled energy scenario termed the policy-adjusted Integrated Resource Plan (IRP) 2010–2030. The, most recent, IRP proposed 8.4 GW new-build installed wind capacity for South Africa by 2030 (DoE, 2011). While a significant percentage of this proposed capacity is expected to be generated by large scale wind turbines, the IRP suggested contributions and further research in off-grid technologies and activities (DoE, 2011). Presently, the off-grid small wind technology is at infancy in South Africa, with very little development recorded (Szewczuk, 2012; Otto, 2013; Milazi, 2015), and if this technology is to contribute to the proposed GW, then the sector needs to be further researched and developed. Further growth in this sector will involve devising a development path, and this will require an analysis and the development of key factors.

In seeking a development path for the small wind sector in South Africa, two developmental factors – policy and technology performance – were considered for exploration. Schwerin (2010) expressed that, key factors which often caused the failure or underdevelopment of renewable energy projects include inconsistent government policies, poor technology, missing planning and maintenance capacities. Regarding policy, concerns include level of supportive legislation, continuity and consistency, stability, administrative hurdles, bureaucratic and non-transparent authorisation and permitting procedures (Beck *et al*., 2004; Finlay-Jones, 2007; Gross *et al*., 2010). Technological factors affecting the viability of distributed wind include scarcity of turbine choices, relatively poor productivity, siting, and burdensome interconnection rules (Kwartin *et al*., 2008).

Frost and Sullivan *et al*, (2013) indicated that some policies do exist to promote small wind generation in South Africa, and some manufacturers are active in the small and medium wind turbine market, with a relatively high degree of local content **(**Szewczuk, 2012). However, little or no known research has evaluated the way in which polices and technology performance have impacted the growth of small wind generation in South Africa (Otto, 2013; Milazi, 2015). Similarly, Edkins *et al*. (2010) recommended that a detailed review of the impacts of the renewable energy policy (beyond the employment benefits in South Africa which their study focused on) is necessary.

Measuring support policies play an important role in overcoming barriers and promoting the expansion of renewable energy (Luthi, 2011), and the relevance of return factors in assessing renewable energy support policies and risk in general, have been recognized in academic literature (Mitchell *et al*, 2006; Blyth *et al*., 2007; Gross *et al*., 2010; Luthi, 2011). Furthermore, small wind turbines operate mostly in low and moderate wind speed areas, thus, their performance and durability need to be established, as a low energy yield is one of the major reasons responsible for continued low penetration (Kwartin *et al*., 2008; U.S. DOE, 2008; Ani *et al*., 2013).

Policymakers, investors, manufacturers, distributors, and academics need the abovementioned information for effective policy design, improved investment and performance design. Hence, in formulating a development path for further growth of the small wind sector in South Africa, with respect to these outlined key factors, the research questions are: *How have the available policies benefitting small wind energy systems (SWES) in South Africa affected the growth of the sector? How has the technology performance of these systems affected the growth of the sector? How can these two factors be better developed to achieve further growth of the small wind sector in the country?*

1.3 Research Aim

This research aims to evaluate the effects of the available policies benefitting small wind energy systems and the technology performance of these systems on the viability and future growth of the sector in South Africa, and to propose a sustainable alternative development path to overcome the limitations.

The study is being built on the assumption that, to develop a path that will further grow the small wind sector and encourage future uptake of the technology, South Africa needs to study the effect of available policies and technology performance of small wind installations on the viability and future growth of the sector, determine the limitations, and subsequently, establish corrective policies. This thesis is loosely modelled after these theses: *Performance and Policy Evaluation of Solar Energy Technologies for Domestic Application in Ireland (Ayompe, 2011); Effective Renewable Energy Policy: Empirical Insights from Choice Experiments with Project Developers (Luthi, 2011)*.

The concept of technological development for new and emerging technologies is applied to this study. Small wind turbine is an emerging electricity-generating technology, thus the diffusion of innovation theory guided the theoretical framework. The three phases of development with regard to the diffusion of small wind technology were used to structure the data for further analysis and formulate a development path. The following chapters of this thesis elaborate on these aspects. For an improved understanding of the development and development processes (path), it is useful to analyse the main mutual cause-effect relationships of a system (SWES). A systematic way of doing this, could be to split this system into developmental "objectives" (research objectives), i.e. desirable development achievements (Bellu, 2011).

1.4 Research Objectives

The research objectives of this study are the following:

- Evaluate the effect of the available policies benefitting SWES in South Africa on the viability and future growth of the sector, and the influence of policy factors (return and risk) on the level of deployment and development.
- Evaluate the techno-economic performance (energy productivity and economic viability) of the SWES in different locations in South Africa, and their impact on the viability and future growth of the sector.
- Propose an alternative near-term development path to temporarily address limitations identified, stimulate an increase in demand, and quickly grow the small wind sector in the country.
- Further propose a long-term development path, leading to cost-competitiveness of the systems, commercial viability, and sustainable growth of the sector.

1.5 Thesis Statement and Hypothesis

The viability and future growth of the small wind sector in South Africa is related to the evaluation of the presently available policies benefitting the systems and technology performance, and the proposition of a sustainable alternative development path to overcome the limitations identified.

This study is evaluating and establishing two developmental variables: policy and technology performance. Thus, the hypotheses being tested and verified are:

Alternative Hypothesis H_1

The viability and future growth of the small wind sector in South Africa is limited by the presently available policies benefitting the systems and technology performance, and therefore requires a sustainable alternative development path to overcome the limitations.

Null Hypothesis H_0

The viability and future growth of the small wind sector in South Africa is not limited by the presently available policies benefitting the systems and technology performance, and therefore a sustainable alternative development path to overcome the limitations is not required.

Sub-hypotheses

- Policy

H_1: The viability and future growth of the small wind sector in South Africa is limited by the presently available policies benefitting the systems.

H_0: The viability and future growth of the small wind sector in South Africa is not limited by the presently available policies benefitting the systems.

- Technology Performance

H_1: The viability and future growth of the small wind sector in South Africa is limited by the technology performance of the systems.

H_0: The viability and future growth of the small wind sector in South Africa is not limited by the technology performance of the systems.

If all the success criteria for the sub-hypotheses of this research study are met, then the *Hypothesis H_1* would have been fulfilled. However, if one of the criteria is not met, then the *Hypothesis H_0* holds.

1.6 Research Methodology

A mixture of both qualitative and quantitative methods were utilised in this study. For the policy evaluation, a case study design was applied, while collecting data through a literature review and structured interviews. The case study approach is an empirical research method in which a contemporary phenomenon is studied within its real life context, whereby the boundaries of the phenomenon and the context are not clear and evident, and in which a number of sources of information are used (Yin, 1994). The evaluation of the technology performance involved a combination of quantitative mathematical models and qualitative expert interviews. A variety of sources were used for the data collection and analysis. The literature review involved an extensive review of documents (energy journals, legislative acts, doctoral theses, academic publications, policy documents, government funded research reports) in South Africa and beyond. The interviews involved two approaches – semi-structured and structured questionnaires (Mintrom, 2003). The interviews were used for in-depth data collection, and complemented the information obtained from the literature. The data were also analysed to clarify the results, and subsequently, a sustaining alternative development path that would activate the future and sustainable growth of the small wind sector was developed and validated.

1.7 Contributions to Knowledge

This thesis contributes to research and addresses the concerns identified in the problem statements and analysis of this research study.

- By running the available policies benefitting SWES in the country through the return-risk framework tests, this thesis establishes new insights into the effects of these policies on the deployment and development levels of the SWES. Furthermore, the importance of the two factors (return and risk) in policy formulation was established. Measuring support policies is essential in removing barriers and advancing the growth of renewable energy (Luthi, 2011). While support policies are required to successfully grow renewable technologies (Schwerin, 2010; Gross *et al*., 2010; Ayompe, 2011), and studies have demonstrated the availability of some policies benefitting small wind generation in South Africa (Frost & Sullivan *et al*, 2013), there is no known research that has evaluated the way in which these polices have impacted on the growth of small wind generations (Szewczuk, 2012; Otto, 2013; Milazi, 2015). Besides, Edkins *et al*. (2010) had recommended that a detailed review of the impacts of renewable energy policy (beyond the employment benefits in South Africa that they researched) is necessary.

- This thesis establishes new findings regarding the energy and economic performance parameters of small wind systems under different weather conditions in the country. These findings constitute new information on parameters such as energy productivity, costs of small wind-generated electricity, and economic viability. The cost of generated electricity is the most significant input parameter in the investment and economic analysis of electricity generating facilities (Simic *et al*., 2013). Deriving these economic and investment parameters involve analysing and determining the payback period, net present value, and levelised cost of energy of two commercially available small wind turbines in 12 different geographical locations, using standard economic models. The energy productivity of these turbines is derived by combining the wind speed distribution of all the considered sites with the power curves of the turbines.
- Furthermore, this thesis formulates an alternative near-term development path, a temporary solution proposed to address the high investment costs revealed by the study (financial assistance to reduce up-front cost burden on consumers), act as a first stimulus to demand increase, and quickly grow the sector. This near-term development path (market pull), which is incentive-oriented, provides a new model for granting investment capital subsidies to consumers, which include the percentage of investment costs that can be granted in different locations of the country and the percentage capital subsidies against different Levelised Cost of Energy (LCOEs). Also, new data of cumulative installed capacities were projected for this path.
- The thesis further formulates a sustainable development path, a proposed long-term solution, expected to lead to cost reductions of the systems, cost-competitiveness, and sustainable growth of the sector, based on the free market theory. The long-term development path (technology push) computed new capital costs at which the LCOE of the systems becomes competitive with both conventional generation and solar PV in different locations; projected the future

reduced costs of the systems, and provided an estimation of the cumulative capacity at which specific reduced cost of the systems would be achieved. The learning curve model is applied in projecting the cost reductions of the system.

1.8 Scope of Research and Thesis Outline

This study evaluates and determines the impact or effect of the available policies benefitting small wind generations in South Africa on market growth and the policy factors (return and risk) that determine these policies; examine the technology performance of these systems and establish their viability; lastly it proposes a development path and recommendations for further growth of the sector in the country. This thesis is structured into eight chapters.

Chapter 1 introduces the thesis and the scope of research. The research problem statement, aims and objectives, thesis statement, research hypotheses, and research methodology are equally defined. The literature review in Chapter 2 identifies the research documentations in relation to wind energy development in South Africa and beyond. Chapter 3 describes the design and methodology used in conducting the research. It presents the processes, methods, and designs used for data collection, data analysis, and the results. The research analyses and results in Chapters 4 and 5 comprise the evaluation of the different data collected from various sources and the presentation of the results of the research study. Chapter 6 provides an alternative development path to overcome the limitations identified, and realises viability and sustainable growth of the sector in the country. In Chapter 7 the validation of the proposed development path for SWES is presented. The conclusions in Chapter 8 collate and consider the findings of the study against the initial objectives. Furthermore, the chapter presents recommendations, and identifies further research possibilities. Based on this principle, the research study thereby proceeds to successive chapters, beginning with a review of related literature.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

Coal is a resource that is abundantly deposited in South Africa, and it constitutes the largest share of the nation's electricity generation. The electricity generation through coal contributes to the country's high carbon emissions, making South Africa the 14th highest emitter of GHG in the world (Ayodele *et al.*, 2012a). Emissions from coal combustion (263,783 Gg of carbon dioxide equivalents or 74.7% of total emissions) are the largest contributor to total emissions (Blignaut *et al.*, 2005). In response to global energy price instability, supply insecurity, and environmental pollution concerns, the country is moving towards other sources of clean energy, thus, generating more energy from renewable resources. The application of renewable energy for generating electricity in South Africa is expected to have tangible environmental benefits (NER, 2000; Winkler, 2005).

Renewable energy sources are natural, free and limitless, and they expectedly possess the most favourable solution to climate change impacts and other energy problems (Shawon *et al.*, 2013). These sources of energy have grown steadily since the 1990s, accounting for 32% of global electricity production in 2008 (IEA, 2010). Renewable energy industries have witnessed faster growth rates than most other industries within the past decade, and the sustained growth of renewable energy has the potential to address numerous aspects of a nation's economic, environmental and social goals (Thorstensen *et al*., 2013). This fostering of renewable energy sources in electricity markets has led to a significant utilization of wind energy (Weigt, 2009).

The power of wind is a clean, inexhaustible, and renewable source of energy (Rehman & Sahin, 2012). The application of wind as a source of energy dates back to between the late 1800s and the early 1900s when farmers and ranchers in the U.S. used windmills for irrigation, pumping water, grinding, charging batteries, powering lights, radios, etc. (Ozgener, 2006). Wind energy is known to generate and provide electricity in remote locations, decrease fuel dependence, and reduce GHG emissions (Rhoads-Weaver & Forsyth, 2006; Merriam, 2009). The availability of modern technology and the technical expertise of engineers are making wind turbines more dependable, sustainable, and affordable for consumers. Moreover, by investing in the newly developed technologies of wind energy generation, it creates a more reliable and competitive energy market, new employment opportunities, and increases the diversity of the energy supply, thus, contributing to energy security (Sauter & Watson, 2007; Heagle *et al*., 2011). The worldwide growth of wind energy has been impressive. By the end of June 2012, the worldwide wind capacity reached 254 GW, the most coming from China and the US, with installed capacities of 67.77 GW and 49.80 GW respectively (Mostafaeipour, 2013). Ayodele *et al* (2012a) predicts that 12% of the world electricity may come from wind power by 2020.

Despite the fact that wind energy projects across the world had mainly been centred on wind farms comprising many large scale turbines, the small wind sector is experiencing expansion more recently (Minderman *et al.*, 2012). Small wind energy systems (SWES) provide clean, renewable power for on-site application and reduce the burden on the power grid while providing energy security for households, businesses, communities, farms, public facilities, and remote locations in the developed and developing world (Forsyth & Baring-Gould, 2007). SWES possess less generating capacity than the large scale utility turbines located on wind farms, however their reduced costs and additional versatility enable a broader application of their wind power (Querejazu, 2012).

This chapter identifies the research documentation in relation to small wind development in South Africa and beyond. It specifically documents the history and growth of the system, technical description and operation, markets and applications, environmental concerns, and the roles institutions and actors played on the functionality of the small wind industry in the country.

2.2 Small Wind: History and Growth

The definition of a small wind system varies across jurisdictions, laws, and incentive programs (Heagle *et al.*, 2011). In the UK, a small wind turbine is legally defined as a unit that can generate up to 50 kW (DTI UK, 2004; Minderman *et al*., 2012), while the US refers to a small wind turbine (SWT) as a turbine generating less than or equal to 100 kW (AWEA, 2011). Small wind turbines were historically perceived to be in the range of under 10 kW in South Africa (Ackerman & Soder, 2000) and 1.5 kW turbines were most commonly used (Whelan & Muchapondwa, 2009). Small wind turbines are applications primarily used for distributed generation, generating electricity for on-site use, rather than electricity transmission from large utility power stations or wind farms (Querejazu, 2012).

The recognition of SWT as a matured technology have been in existence for several decades, originally receiving acceptance in the early 20th century among small farmers and ranchers that were already familiarised with mechanical water pumping systems powered by wind in the Midwest (Forsyth & Baring-Gould, 2007). These systems were installed on several rural farms to produce and supply energy prior to the initiation of huge US rural electrification projects. The first commercial model of a small wind turbine was assembled by Marcellus Jacobs in 1922, hooking a fan blade from an old water pumping windmill to the rear axle of Model T car (Asmus, 2003). These model designs had a rated capacity of 1 to 2 kW, contained three blades, and were widely accepted in the rural areas that had not yet an installed utility grid. As the rural grid electrification projects increased largely during the depression and World War II, the quantity of the small wind systems declined, but rose again in recent years due to migration to rural and off-grid regions (Forsyth & Baring-Gould, 2007).

Modern small wind generation initiated in the 1970s during a period of energy crisis, when consumers reapplied the refurbished vintage designs from the 1930s, where after they manufactured new designs from the old ones, from where they progressed to new small wind technologies designed to address modern requirements (AWEA, 2002). Many of these systems were grid-connected. The systems of today lean on the aerospace technologies, possessing advanced, though mechanically simple, robust designs, which enable reliable operations for a useful lifetime of between 20 and 30 years (AWEA, 2002). The simply structured, compactly designed, portable, little noise producing SWES are currently essential technological developments for the extraction of power from the wind in rural, suburban, and urban settlements where the installation of large scale turbines is restricted (Hirahara *et al*., 2005; Singh & Ahmed, 2013). In practice, these turbines operate under similar conditions like the large scale turbines, requiring open and exposed sites and good wind speed, though lower (Forsyth & Baring-Gould, 2007; Carbon Trust, 2008).

The total installed capacity of small wind turbines is increasing, supplying electricity to isolated consumers, grid-connected households and other on-grid systems feeding excess electricity into the grid (Simic *et al*., 2013). This increase in installed capacity of small wind generated electricity is predominantly found in the US and the UK, with the US market being accountable for almost 50% of the global market (Whale *et al*., 2013). The total installed capacities for the US and the UK in 2010 were 170 MW and 40 MW respectively (Renewable UK, 2011; Minderman *et al.*, 2012; AWEA, 2011), with the global capacity totalling over 440 MW (WWEA, 2012). However, the small wind energy industry in South Africa is still in infancy, with an installed capacity of about 0.56 MW (Szewczuk, 2012). A few turbines have been erected on premises in the country connected to the grid, but most turbines were typically installed off-grid (Szewczuk, 2012). Currently, there are about 250 companies in 26 countries that are manufacturing small wind turbines, with the US hosting more than a third (Rolland & Auzane, 2012). Rolland and Auzane (2012) predicts that the global market for small wind energy technologies will more than double between 2010 and 2015, costing USD 634 million, with much of this growth expected to be in developing and emerging markets.

Although economic and environmental factors are still principal concerns, the demand for small wind turbines is continually being driven by a combination of economics (payback period or IRR, financial hedge against rising prices of conventional electricity, financial stability compared to the volatile prices of conventional electricity); practicability (reliability of electricity supply, natural synergism with solar PV technology, diversity of applications including those remote and off-grid); and values (environment, independence, image enhancement, consumer choice, self-reliance, do-it-yourself, and high visibility particularly for commercial consumers) (AWEA, 2010). The application of small wind turbines as credible alternative sources of electricity should be widely promoted in the developing countries, as the success story of small wind development in China validates this potential (Rolland & Auzane, 2012).

2.3 Technical Description and Operation

The technological design of a small wind turbine is less matured and evidently differs from large wind turbines in terms of the control of and the electrical and the rotor design (EWEA, s.a). However, small wind turbines operate like large scale wind turbines, although at lower wind speeds and heights. A wind turbine converts the power of the wind into electricity when the movement of the air past the turbine blade results in an aerodynamic force of lift, causing the rotation of the blades, resulting in the conversion of the mechanical energy of the rotating blades into electricity by a generator inside the turbine (Manwell *et al*., 2009; Querejazu, 2012). Most SWTs have a permanent magnet generator, thus, no need for a gearbox (Rolland & Auzane, 2012). These generators are prevalent since they have the advantage of eliminating the requirement for brushes, which need to be replaced periodically (Refocus, 2002). The generators produce alternating current (AC), and this AC has to be rectified into direct current (DC) by a bridge rectifier. The DC voltage enables the turbines for battery charging.

Small wind turbine can be a horizontal axis wind turbine (HAWT) or a vertical axis wind turbine (VAWT). The two can be compared in terms of productivity and efficiency, ease of maintenance, environmental safety, and aesthetic design (Ahmed, 2013).

2.3.1 Horizontal Axis Wind Turbine (HAWT)

The most commonly used small wind turbine currently is the horizontal axis model, due to its superior efficiency and generation capabilities (Refocus, 2002; Querejazu, 2012; Brosius, 2013). A horizontal axis wind turbine consists of a rotor, a generator, a mainframe, and usually a tail. The main rotor shaft and electricity generator are located at the top of a tower and must be directed into the wind (Brosius, 2013). Most turbines possess a gearbox to control the rotor speed, and the rotor usually consists of two or three blades, which are generally made of wood or fibre glass to obtain the required combination of strength and flexibility (Refocus, 2002). The structural backbone of the turbine is the mainframe, containing the “slip-rings” that connect the rotating turbine and the fixed tower wiring. As mentioned previously, these HAWTs must be directed into the wind to generate power, with simpler models using a weather vane behind the blades to realise this, while more complex models use wind sensors and a motor (Querejazu, 2012). The tail aligns the rotor into the wind and can be a part of the overspeed protection. The turbine is usually mounted upwind of the tower, since the tower creates turbulence behind it (Brosius, 2013).

The HAWT possess a high efficiency when directed in the direction of the wind. However, the blades fail as they approach the designed maximum limit speed (Ahmed, 2013). Recent technological advances have improved many of the features of the HAWTs, as newer models can generate more power with fewer blade rotations per minute (RPMs) leading to improved efficiency and reduction in the noise produced by the turbines (Querejazu, 2012). Since rare earth magnets are put in the generators of these newer models, generators can be smaller and lighter, and the rotors are now equipped with brakes or pitched blades that protect the small wind turbines from getting damaged by high winds (Querejazu, 2012).

2.3.2 Vertical Axis Wind Turbine (VAWT)

The vertical axis wind turbine (VAWT) was introduced by Darrieus in 1931 (Darrieus, 1931; Saeidi *et al.*, 2013). His patent contained both the curved blade and the straight blade. These turbines are designed differently, with the turbine blades rotating around a vertical rotor shaft. The principle benefits include the ability to generate power regardless of the direction of the wind, operation at lower wind speeds, easy design and manufacturing, and it can be placed lower to the ground enabling easy access for maintenance and repair (Querejazu, 2012; Brosius, 2013; Ahmed, 2013; Saeidi *et al*., 2013). However, as a result of their circular cycle of motion, the vertical axis wind turbine often have a portion of its blades constantly backtracking against the wind, making efficiency its main limitation (Ahmed, 2013). Their power output is less as they operate at lower speeds, and the blades are more exposed to damages due to high winds (Querejazu, 2012). Furthermore, their start-up is deficient, requiring an auxiliary system or a modification to the generating system (Kirke, 1998). They may generally be preferred in environments with less available space, or where wind speed and direction are inconsistent (Querejazu, 2012).

The VAWTs can be further categorised into three basic types, namely: Darrieus, Savonius, and giro mill. The Darrieus possess a good efficiency, but generate a large torque ripple, the cyclic stress on the tower adds to poor reliability, and generally it needs some external power source to start rotating due to the low starting torque it possess (Brosius, 2013). The Savonius are drag-type devices that have two (or more) sails or fins, are self-starting, and sometimes have long helical scoops to give a smooth torque. They are used in anemometers, *Flettner* vents (commonly seen on bus and van roofs), and in some high-reliability low-efficiency power turbines (Brosius, 2013). The giro mills are a subtype of the Darrieus turbine, having straight blades, with a variable pitch to lessen the torque pulsation and increase the starting torque (Brosius, 2013). These lead to lower blade speed ratio; a higher performance coefficient; and more efficient operation in turbulent winds.

As a large number of these small wind turbine systems are being installed where the wind is usually weak and unstable as a result of the presence of buildings and other obstructions (Wang *et al.*, 2008), there is an increasing interest in and calls for the development of advanced small wind turbine technologies in the wind energy community (Kumbernuss *et al*., 2012; Saeidi *et al.*, 2013),. To realise a reasonable power output from the mentioned variable environments, and to rationalise such installations economically, the turbines need to be specially designed to improve their energy capture, specifically at low wind speeds and turbulent wind conditions (Wang *et al.*, 2008). More recent studies have focused on designing wind turbines specifically for urban applications (Booker *et al*., 2010; Drew *et al.*, 2013). Balduzzi *et al.* (2011) have conducted a feasibility analysis on the installation of Darrieus vertical axis wind turbines on the rooftop of a building. Similarly, the analysis of the furling behaviour of small wind turbines was studied by Audierne *et al*. (2010) and Saeidi *et al.* (2013). These studies have indicated the need to produce site-specific small wind turbines, which combine novel designs and new production materials for an improved performance. Fuglsang *et al*. (2002) described a European project on the site-specific design and optimization of wind turbines in which the cost of energy was reduced by up to 15% through an increase in annual energy yield and a reduction in manufacturing costs. However, full domestic utilization of wind turbine technology will only occur when these systems operate efficiently at low speeds, are safe, produce little or no noise, and possess the capacity to run without shutting down under moderate to extreme variations in wind conditions (Ahmed, 2013).

Furthermore, there is also a surge of renewed interest in the determination of SWT power curves, rated wind speeds, reliability, etc. (Gottschall & Peinke, 2008; Whale *et al.*, 2013). Historically, SWT manufacturers have not had to undergo the same stringent certification procedures than large wind turbine manufacturers, and test data are often provided by manufacturers only without independent verification. Bowen *et al*. (2003) showed that there are often notable discrepancies between measured power curves and those supplied by the manufacturer. On a national level, the American and British Wind Energy Associations have both produced safety and performance standards for SWTs (AWEA, 2009; Renewable UK, 2008). The US and the UK have established frameworks for the certification of SWTs, through the Small Wind Certification Council (SWCC) and the Micro-generation Certification Scheme (MCS) respectively (Whale & Malla, 2011; Whale *et al*., 2013). This standardization was taken to an international level with the formation of a Small Wind Turbine Liaison Program coordinated by the International Electro-technical Commission (IEC) and the International Energy Agency (IEA) jointly. The program has led to a complete revision of the IEC61400-2 (IOS, 2005), the international standard for small wind turbines, and the publication of recommended practices on the testing of SWTs (IEA Wind, 2011). Currently, South African firms manufacture small wind turbines and components with a relatively high degree of local content. Kestrel Renewable, a local firm, manufactures small wind turbines that are 100% local that they also export. Their e400nb model turbine is UK (Micro-generation Certification Scheme) and US (Small Wind Certification Council) certified. Rigorous testing for small wind turbines consists of design data testing, power and acoustic performance testing, and safety and duration testing.

Generally, wind is fastest high in the air, as there is nothing slowing or obstructing the wind's movement. On the other hand, the speeds are practically nil close to the ground as a result of the drag effects arising from the roughness of the ground (Carbon Trust, 2008). There is a logarithmic increase in wind speed with increase in height, thus a marked acceleration for a small distance just above the ground and a more gradual speed-up thereafter, known as the shear effect (Carbon Trust, 2008). The higher a turbine is mounted, the greater the expectation of the power output from that turbine.

2.3.3 System Siting

The siting of a small wind turbine is of great importance when installing the system to ensure proper performance and reliability (Rolland & Auzane, 2012). Thus, the siting of the systems should be away from major obstacles with clear access to wind in order to be productive and avoid turbulence which lowers performance (Refocus, 2002; Rolland & Auzane, 2012). Excessive turbulence, that is most severe close to ground level, may damage and reduce the lifetime of small wind turbines (Refocus, 2002). Small wind systems should be installed on the top of smooth hills or on high towers (Rolland & Auzane, 2012), as wind speed increases with an increase in height (Refocus, 2002). Figure 2.1 indicates the siting of small wind turbines exposed to a wind flow and obstructions. Furthermore, the energy outputs from turbines possibly increase with a distance increase from the city centre (Drew *et al*., 2013). Generally, the installation of a wind turbine on a tower should be at least 9 m high and no obstacles within 90 m, with small wind turbines normally requiring smaller towers than larger turbines (Refocus, 2002). Additionally, the small wind turbine can equally be pole and roof-mounted when siting the system. The component breakdown for both pole and roof-mounted small wind turbines are presented in Figures 2.2 and 2.3 respectively.

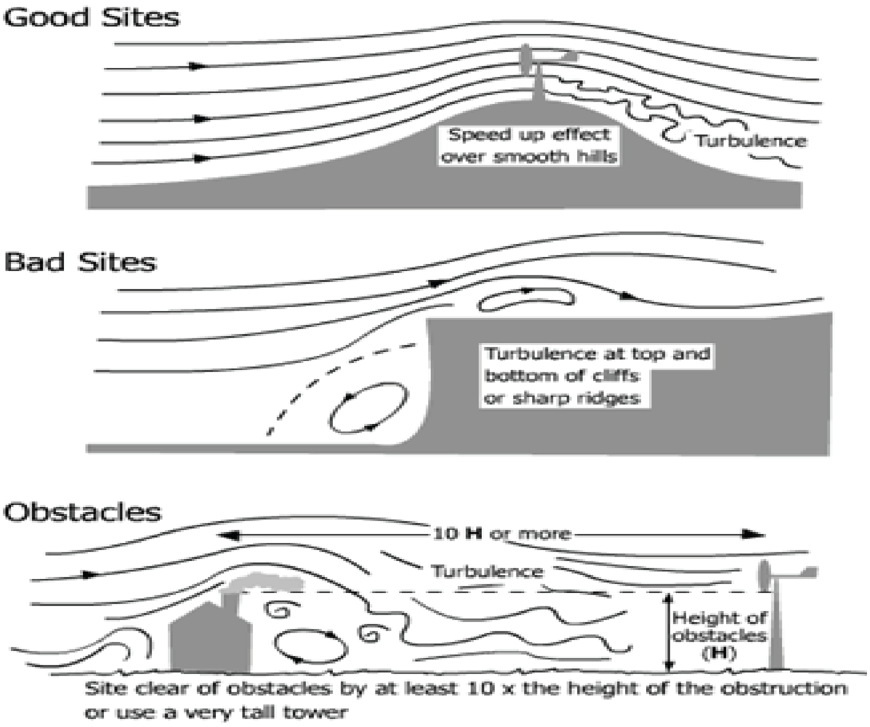

Figure 2-1: Small wind turbine siting and wind flows (Rolland and Auzane, 2012)

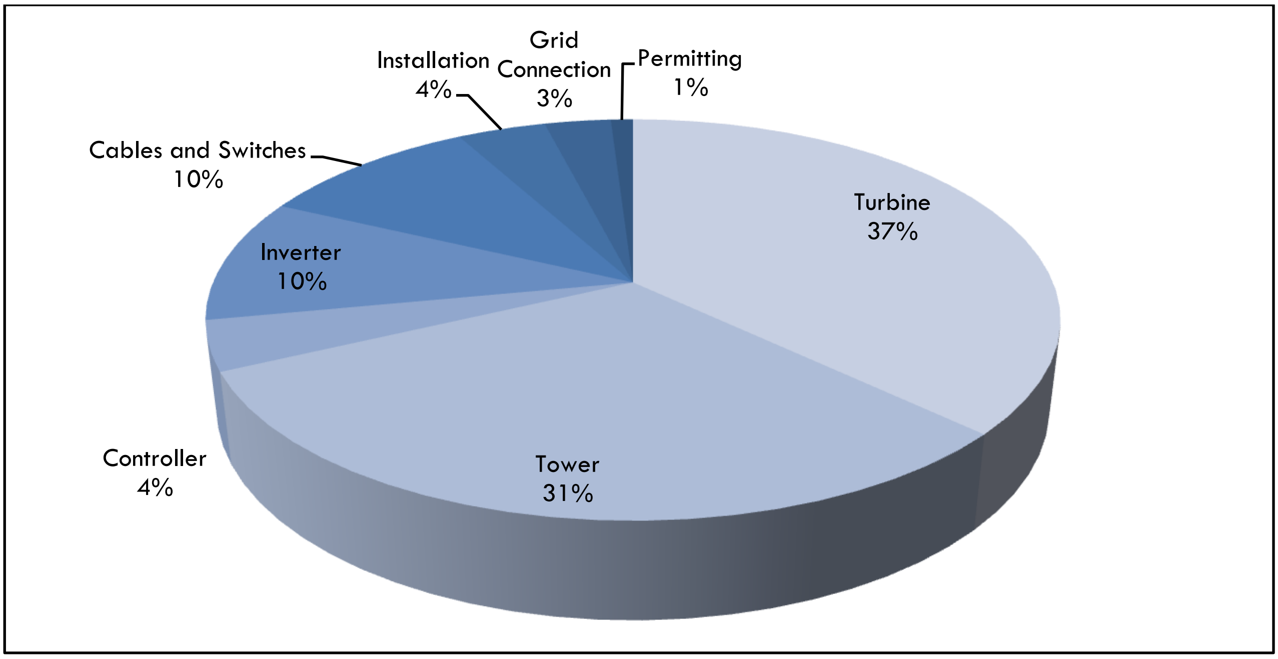

Figure 2-2: Component breakdown for pole-mounted small wind turbine (Frost & Sullivan et al, 2013)

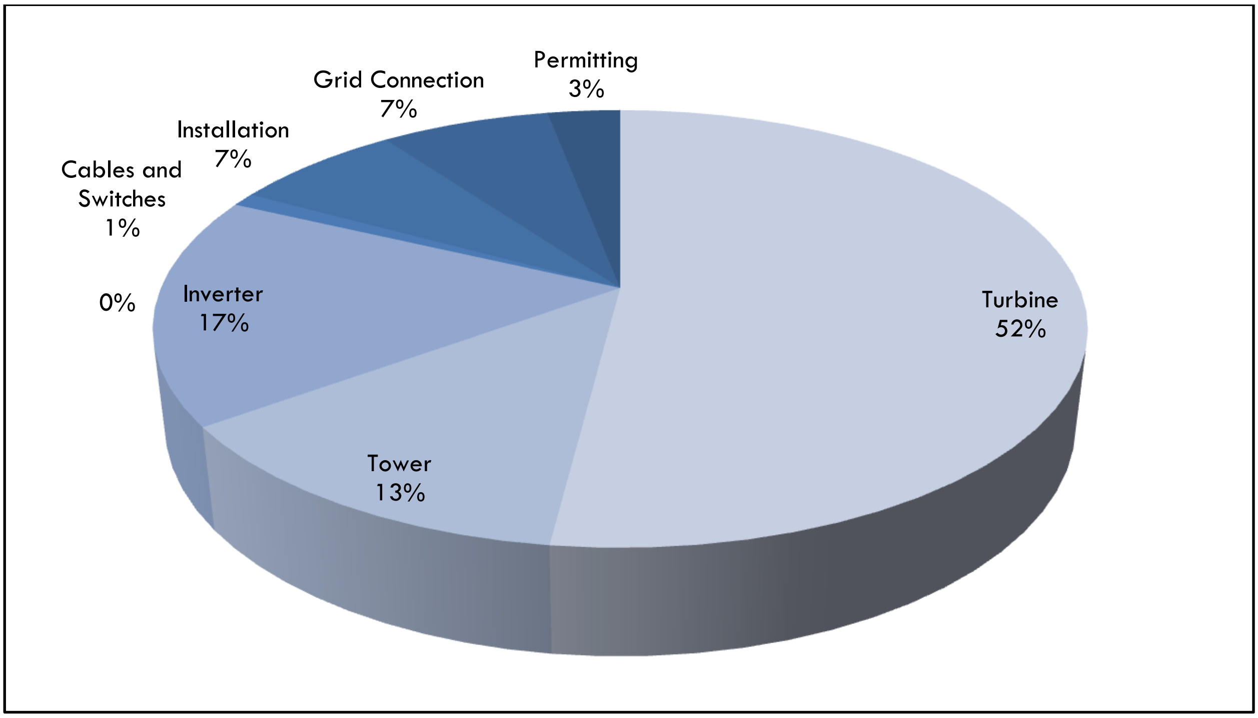

Figure 2-3: Component breakdown for roof-mounted small wind turbine (Frost & Sullivan et al, 2013)

2.4 Markets and Applications

The nature of the supply chain for small wind technologies, from technical design, manufacturing, distribution and installation, as well as marketing and sales activities, is different than that for large scale units (DECC, 2009). Small wind energy systems are designed in many sizes to meet the energy need and the resources available to the consumers. Four market segments were identified and documented for small wind turbine applications in this review. These market segments include the residential, community, commercial, and agricultural market sectors.

2.4.1 Residential Market

Residential small wind generation systems are single micro-sized turbine systems installed on the house's side of the electrical meter to supply energy directly to the home for residential applications, and are usually building mounted or freestanding (Forsyth & Baring-Gould, 2007; Willcock & Appleby, 2009). This market provides for individual homes, rural homesteads, suburban homes, multi-family dwellings, local authorities, housing associations, and small community applications. Most consumers install these systems to meet their energy needs at remote sites away from the grid or to be energy independent or self-sufficient. These turbines are usually integrated with other components, such as storage and power converters.

The potential for residential consumers in South Africa is quite huge. The residential market sector accounted for 20.4% of the nation’s electricity consumption in 2006 (DoE, 2010). According to a survey on energy for the residential sector in South Africa by the Department of Energy (2013), the country had about 13.4 million households in 2012, with 9.8 million households having electricity. Approximately 3.4 million households are without electricity, this entails 1.2 million households in informal settlements and 2.2 million households in formal settlements.

2.4.2 Community-Wind Market

This involves the application of single or multiple installations of micro-sized or small sized units to provide power to isolated communities, villages, mini-grid, public buildings, schools, public lighting, entertainment centres, churches, mosques, and municipal services (Forsyth & Baring-Gould, 2007; Willcock & Appleby, 2009). These systems are fully/partially owned by or used for the community. The installation of community wind systems can be collective aspirations of community stakeholders to benefit the public, for educational or ethnic purposes, for a neighbourhood, or for co-operative commercial entities. Communal wind projects can strengthen communities, encourage local control of power management, increase local investments, generate more local jobs, widen local impacts, and promote environmental responsibility (Forsyth & Baring-Gould, 2007; Querejazu, 2012).

2.4.3 Commercial Market

The commercial market for small wind systems comprises of the installation of usually a single system to supply businesses and small industrial applications with wind-generated electricity. The loads provided by this sector are larger than most residential applications (Forsyth & Baring-Gould, 2007). The small wind systems in the commercial sector serves supermarkets, office buildings, financial institutions, retail outlets, recreation and tourism activities, universities and colleges, hospitals, petrol stations, museums and other non-industrial activities.

2.4.4 Agricultural Market

Wind energy application in agriculture has a history of more than 1 000 years (Forsyth & Baring-Gould, 2007). From milling, food processing, irrigation, land reclamation to the transportation of goods from source to market by sailing vessels and railways, wind energy was widely accepted as a source of energy. Wind power is being used to directly or indirectly desalinate sea or brackish water, using reverse osmosis, electro-dialysis, or other desalination technologies. Mahmoudi *et al.* (2009) concluded that a brackish water greenhouse desalination unit powered by wind energy is a good solution for desalting groundwater for irrigation purposes, creating the proper climate to grow valuable crops, cooling the produce storage rooms, and also powering electrical equipment such as pumps, ventilators and fans. An overview of the markets and the possible installation characteristics are provided in Table 2-1.

Table 2-1: Market characteristics for small wind energy systems

Market	Setting	Pico-Wind Turbine ≤ 100W	Micro-Wind Turbine 100W – < 1.5kW	Mini-Wind Turbine 1.5kW – ≤ 100kW
Residential	Households; Multi-family dwellings; Housing Associations; Local Authorities; Estates; Townships	√	√	√
Community	Isolated Communities; Village Power; Mini-grid; public buildings; Churches; Mosques; Schools; Entertainment Centre; Municipal Services		√	√
Commercial	Supermarkets; Petrol Stations; Game Reserves; Banks; Shopping Malls; Colleges; Universities; Library; Office Buildings; Hospitals; Museums; Non-industrial Activities		√	√
Agricultural	Farmhouses; Irrigation; Milling; Food Processing; Desalination		√	√

Source: The author and Willcock and Appleby (2009)

Furthermore, SWTs have a wider range of applications, unlike large-scale systems. The applications can be off-grid, on-grid, or hybrid, in which the system is applied as part of combined installations, e.g. photovoltaic systems, etc. (Willcock & Appleby, 2009).

2.4.5 Off-Grid

Off-grid applications, also known as stand-alone or grid-isolated applications, are referred to as autonomous electrical systems. The systems are used for directly generating electricity, and thus they are not connected to the power grid (Querejazu, 2012; Brosius, 2013). They are solely responsible for the control of voltage and frequency (EWEA, s.a). The simplest off-grid systems use direct current (DC), and by adding an inverter to an off-grid system, the electricity can be converted to alternating current (AC), which allows the turbine to power AC appliances and makes the system compatible with the electric grid (Querejazu, 2012). These simple systems may use battery storage to provide backup power when the wind is not blowing. Other storage devices contain hydrogen, compressed air, and pumped water (Brosius, 2013). An off-grid small wind installation is presented in Figure 2.4.

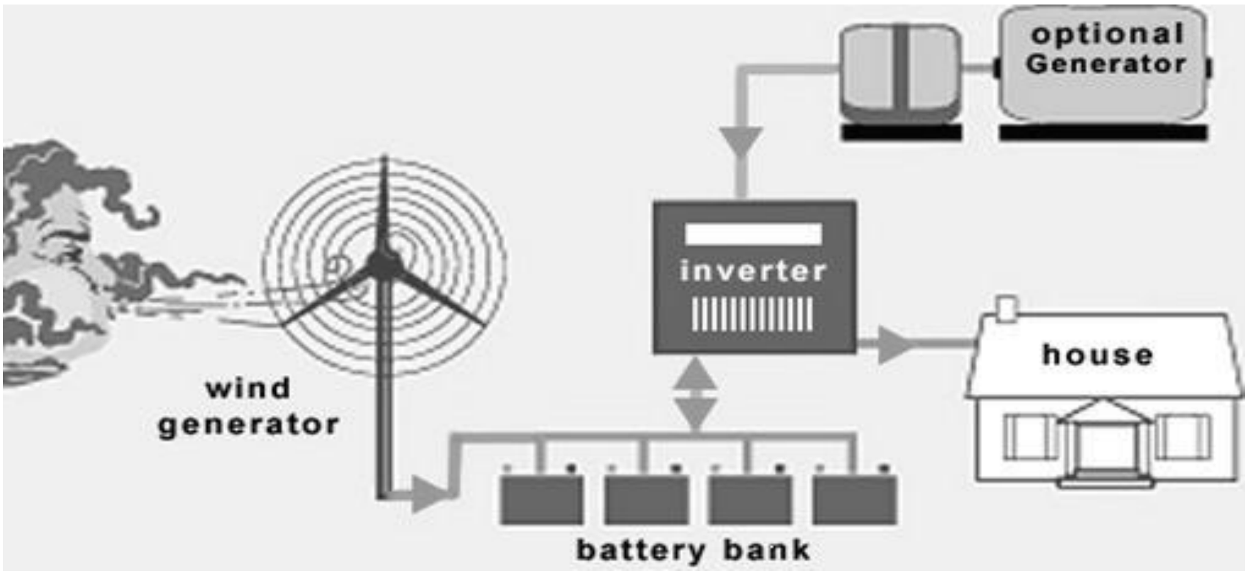

Figure 2-4: Off-grid small wind energy system (Rolland and Auzane, 2012)

2.4.6 Grid-Connected

Grid-connected systems, also called on-grid or grid-tied systems, have small generators connected to a public power grid, and a network operator in charge of its overall control (EWEA, s.a). In grid connection, an inverter is used in controlling the system and supplying electricity to grid voltage and grid frequency (Rolland & Auzane, 2012). Newer turbine models have an in-built inverter, making them compatible with the AC electric grid upon installation (Querejazu, 2012). The quality of electricity exported from the grid-connected system to the grid in terms of harmonic distortion and allowable power factor variations are often controlled by tight requirements. This connection may be protected, for example through “anti-islanding” – a situation where the system safely disposes off excess power if the grid is lost (Wood, 2010). Further, excess power generated this system may be sold back to the utility in some cases (Querejazu, 2012; Brosius, 2013).

2.4.7 Hybrid

A hybrid system refers to a combination of different energy sources, e.g. small wind turbines and photovoltaic systems, as wind energy resource is irregular (EWEA, s.a; Brosius, 2013). Most of these system configurations also include a diesel generator to supply back-up power. Generally, hybrid systems also incorporate batteries for storage and an inverter to control voltage and frequency (EWEA, s.a). This type of system combination is mostly recommended.

2.5 Environmental Impact

Unarguably, small wind power generation has environmental benefits over fossil fuel generations. A primary benefit of using wind-generated electricity is the ability to reduce the levels of carbon dioxide (CO_2) emitted into the atmosphere, which is the GHG that is the major cause of global climate change (US DoE, 2008). However, there are possible fundamental concerns relating to the environment and health as a result of the installation of small wind systems. Environmental and health impacts mostly associated with small wind installations include their visual impact, noise, avian mortality, and electromagnetic induction (EMI). However, these concerns are considered to be largely manageable rather than significant barriers to a project (Kwartin *et al*., 2008).

2.5.1 Visual

The visual or aesthetic appearance of wind turbines generally has a huge impact on public perception and acceptance (US DoE, 2008). This visual impact may be an inclusive factor in gauging site acceptability of small wind energy projects as reactions are subjective and varied, with some people arguing that these turbines are intrusive, and others concluding they are elegant and interesting (US DoE, 2008). Other visual impacts include lighting and flickering, since the rotating turbine blades cast moving shadows causing a flickering that tends to have an effect on nearby residents, as well as the effect of gloss surface blades flashing during rotation (EWEA, 2009a). However, small wind systems do have advantages over large scale systems, as a single locally owned small turbine offers fewer aesthetic issues, and these turbines are mostly sited in rural areas with lower population densities (Kwartin et al., 2008; NREL, 2006).

2.5.2 Noise

The undesirable noise produced by small wind turbines, causes annoyance, nuisance, dissatisfaction, and interference with conversation (Manwell *et al*., 2002). The noise emanates from sounds produced by the turning blades, the gearbox, the generator, and hydraulic systems, and are factors that impact on the rural or urban people depending on the number and distance of residents from the turbine site, and the type of community affected; residential, industrial, tourist, or others (EWEA, 2009a). There is little available quantitative data on small wind turbine noise, due partly to the difficulty in extracting the small sound power levels (SPLs) of well-designed turbines from background noise levels that can fluctuate significantly (Wood, 2010).

2.5.3 Avian Mortality

The impacts of small wind turbines on birds are a major concern. According to Manwell*et al*. (2002) these impacts on birds include death or injury caused by rotating blades; electrocution from transmission lines; alteration of migration habits; reduction ofavailable habitat; disturbance to breeding, nesting and foraging. These impacts vary depending on the bird species, season and site specificity (BirdLife, 2002). Although, Thomas *et al*. (2004) argued that climate change impacts equally endanger significantly the existence of various species of bird and wildlife just as avian mortality.

2.5.4 Electromagnetic Interference (EMI)

Electromagnetic waves produced from the rotating blades of small wind turbines can interfere with or disrupt the signals of communication systems, mostly television reception, aircraft navigation and landing systems, and microwave links (EWEA, 2009a). These interferences possibly occur when turbines are close to transmitters or receivers. However, FM radio, cellular phones and satellite services are very unlikely to be affected (EWEA, 2009a). Likewise, turbine towers may reflect signals, causing interference with the original signal getting to the receiver (Manwell *et al*., 2002).

2.6 Institutions

Institutions are sets of common habits, routines, policies, established practices, rules, or laws that regulate the relations and interactions between individuals and groups (Smit *et al*., 2007). It has been shown that policy plays a major role when it comes to developing countries' process of catching up with industrialized countries (Nilsson & Noren, 2011; Bergek and Jacobsson, 2006). In South Africa, energy production is closely managed and controlled by the government as it is significantly responsible for the socio-economic, security and political development of the country. The government sets rules and regulations for the energy sector, thus, their actions control the growth of wind energy industry, as institutional weakness can be the first primary barrier. The following are the institutions introduced over time in the country to advance wind generation in particular, and renewable energy in general.

2.6.1 The White Paper on Renewable Energy

The White Paper on Renewable Energy was initiated in the middle of 2002 to supplement the White Paper on Energy Policy, recognising the medium and long-term potential of renewable energy. It sets out the government's vision, policy principles, and objectives for promoting and implementing renewable energy, and it is based on the integrated resource planning criterion of ensuring that an equitable level of national resources is invested in renewable technologies (DME, 2003). An annual target of 10 000 GWh of renewable energy, including wind energy, was expected to be added to the final energy consumption in 2013 (DME, 2003), but was never realised. A policy review process order to assess the targets and objectives set was specified five years later.

2.6.2 South African Wind Energy Programme (SAWEP)

The South African Wind Energy Programme (SAWEP) was initiated in 2001 by the Department of Minerals and Energy, in partnership with the Global Environmental Facility (GEF) and the Danish Government to primarily build an industry for wind energy, generate employment, and promote sustainable development (DoE, s.a.). As a result, SAWEP phase 1 was formulated to actualise two key strategic objectives. The first objective was the introduction of the Wind Atlas for South Africa (WASA) to provide essential information and data on wind resources for potential wind farm investors. The second was the development of a Wind Industrial Strategy to establish the country's wind industry and the possibility of local manufacturing of wind turbines and related components in conjunction with Department of Trade and Industry (DoE, s.a.). The WASA project has resulted in the continuous development of a numerical wind atlas and database for South Africa, to realise the first objective. Concerning the second objective local firms now exist, producing small and medium wind turbines manufactured mainly with local materials and designs.

2.6.3 The Revised Balanced Scenario (RBS)

The Revised Balanced Scenario (RBS) was a roadmap published in October 2010 which set out the total proposed power generation fleets to be built between 2010 and 2030. In addition to all existing and committed power plants, the document incorporated a renewable fleet of 11.4 GW (shown in Figure 2-5). The 11.4 GW capacity allocated to the renewable fleet did not specifically categorise the constituents of the renewable energy, and never considered small wind generation. It was later reviewed and refined after consultations with the public and stakeholders.

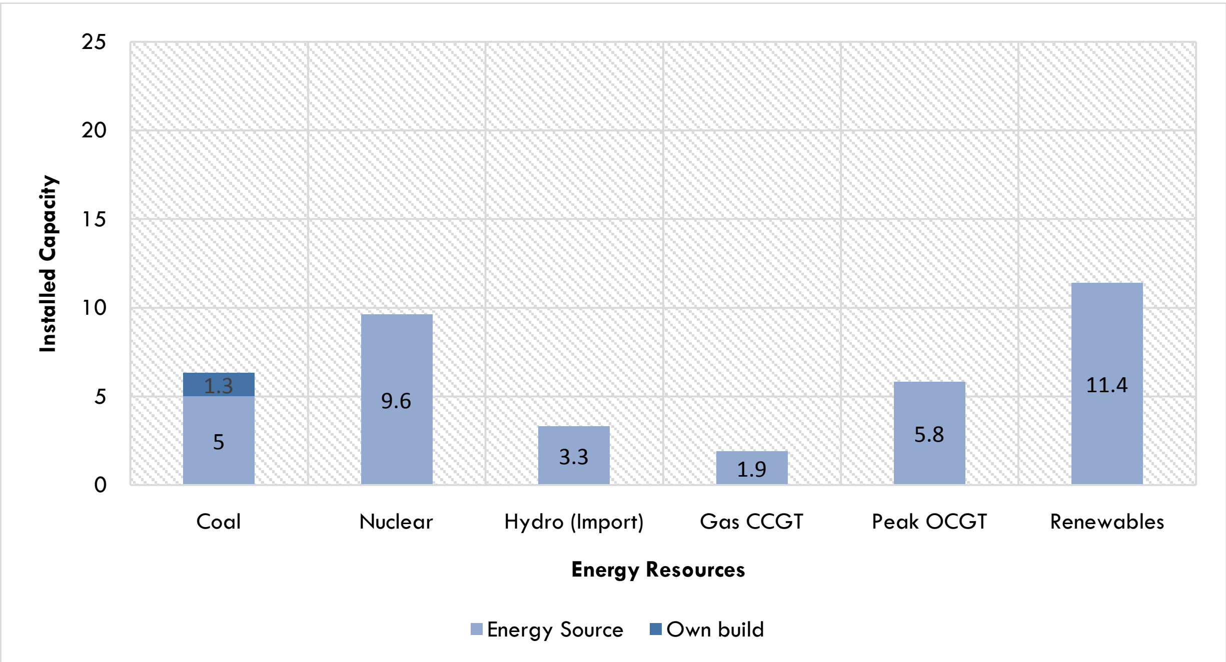

Figure 2-5: Revised Balanced Scenario: new target for renewables by 2030 in GW (DoE, 2011)

2.6.4 The Integrated Resource Plan for Electricity 2010 – 2030

The Department of Energy (DoE) in November/December 2010 re-emphasized the call for a more diversified generation mix by conducting a second round of public participation. The Policy-Adjusted IRP was initiated in 2011 to review, refine and build on the recommendations from the previous Revised Balanced Scenario (RBS) roadmap. The IRP 2010-2030 document, which is the most recent iteration of the Integrated Resource Plan for South Africa on the proposed new build generation fleet for the period 2010 to 2030, witnessed several changes, including the disaggregation of renewable energy technologies to explicitly display solar photovoltaic (PV), concentrated solar power (CSP), and wind energy (as indicated in Figure 2-6). The IRP 2010–2030 proposes a new-build 8.4 GW installed wind capacity by 2030. The IRP yearly wind capacity commitment for 2010–2030 is presented in Table 2-2. While the IRP never allocated any capacity to small wind generation, it however demanded for contributions and further research in off-grid technologies and activities (DoE, 2011).

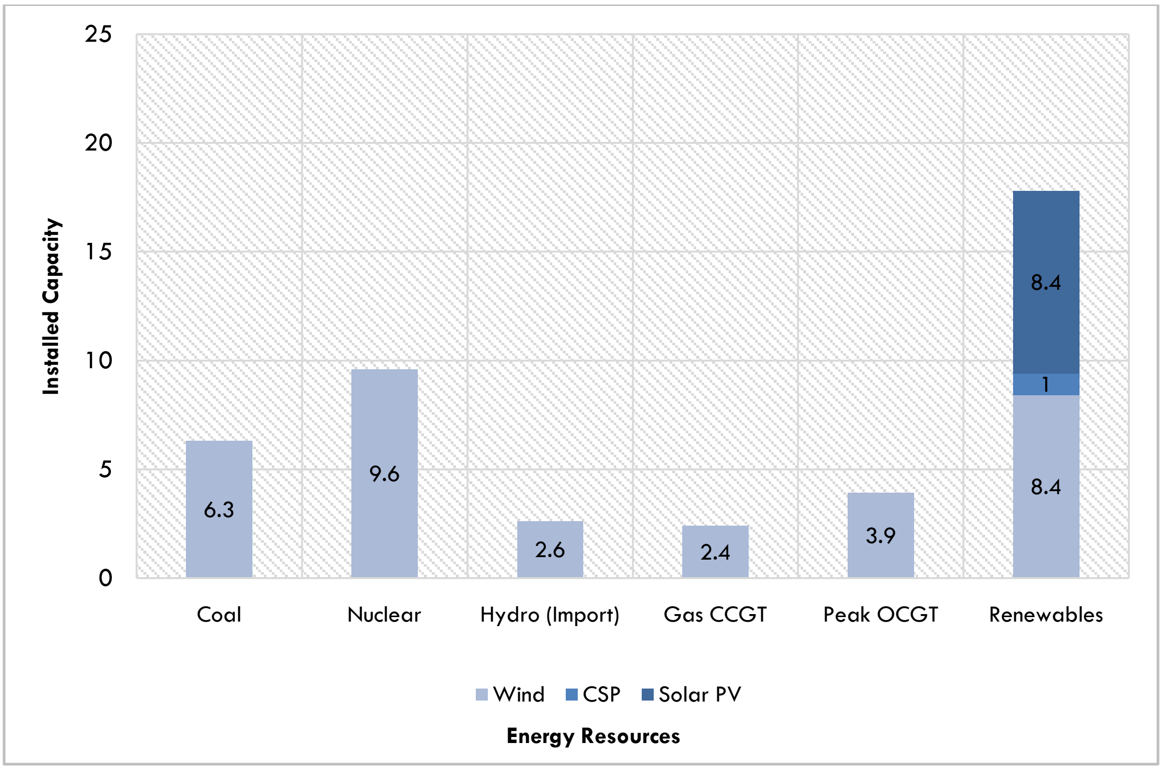

Figure 2-6: Policy-Adjusted IRP: new capacity target for renewables by 2030 in GW (DoE, 2011)

Table 2-2: IRP 2010-2030 yearly wind capacity commitment

Year	Wind Capacity Commitment (MW)
2010	0
2011	0
2012	0
2013	0
2014	400 (Firm commitment necessary now)
2015	400
2016	400 (Final commitment in next IRP 2012)
2017	400
2018	400
2019	400
2020	400
2021	400
2022	400
2023	400
2024	800
2025	1600
2026	400
2027	1600
2028	0
2029	0
2030	0
Total	8400

Source: DoE, 2011

2.6.5 The Integrated Resource Plan (Update)

The Department of Energy had reviewed and updated the last IRP 2010–2030. While the document had been released for public comment and the final document was expected to be published towards the end of 2014. The IRP 2010 is still the valid official plan by the government for new generation capacity until replaced by a new revised IRP and the IRP update is intended to provide insight into critical changes for consideration on key decisions in the interim (DoE, 2013). In the updated IRP document, electricity demand has been projected to reach 345 – 416 TWh in 2030, as against the projected 454 TWh in the IRP 2010. Furthermore, the new total installed wind capacity in 2030 will expectedly become 4 360 MW instead of 9 200 MW, as a result of the review and integration of new wind data into the model.

2.6.6 Renewable Energy Feed-In Tariff (REFIT)

The Renewable Energy Feed-in Tariff (REFIT) is a policy initiated in 2009 by the National Energy Regulator of South Africa to promote wind energy and other renewables. The first phase of the revised REFIT included tariffs for wind, hydro, landfill gas and concentrated solar power, while other renewable technologies were included six months later. The wind tariff, set at R1.25/kW, was guaranteed for 20 years, with 100% of the REFIT to be indexed with inflation, and reviewed annually for the first five years and every three years afterwards so as to prevent a lock-in of inadequate tariffs (NERSA, 2009; NERSA, 2011). However, the next review of the inflation-indexed REFIT tariffs that was expected to be released in 2011 were never announced but was abandoned and replaced with the REIPPPP (Fritz, 2013). The key principles of the REFIT program included: guaranteed access to the national grid; guaranteed purchase price for a fixed duration; etc. (Edkins *et al*., 2010). This policy is expected to encourage potential investors to buy into wind and other renewable energy installations. However, this program was designed and targeted at large scale generation, and does not advance small-scale renewable generation like small wind energy systems at all.

2.6.7 REIPPPP

The Renewable Energy Independent Power Purchase Procurement Programme (REIPPPP) is a policy instrument introduced in August 2011 to accelerate renewable energy development. A competitive bidding system whereby renewable energy project developers submit bids that are weighted 70% on price and 30% on economic development, as well as a 50% threshold for local material and design (DoE IPP, 2012). To allow local investors access to the program, the DoE initially procured 100 MW of “small capacity” projects (1 MW to 5 MW) in a separate stream, which will probably increase to 200 MW subsequently (DoE IPP, 2012)**.** The basic guidelines include: 40% domestic ownership; 30% SME participation in the supply chain; zero threshold local community ownership and 10% target; a range of 1-5 MW; price caps on bids of 1 000 R/MWh for wind; and a construction period and technology cost (Capex) of 8-14 months and 20 000-35 000 R/kW for wind (Frost & Sullivan *et al*., 2013). The program, comprising wind and four other technologies, focused primarily on large-scale generations. The procurement of wind energy projects in the REIPPPP is based on price competitiveness and SWTs cannot compete on this basis (Kruyswijk, 2014).

2.7 Stakeholders

The stakeholders are persons or organisations (Smit *et al.*, 2007) that can exercise a very huge limiting or accelerating influence on development; they include the government agencies, wind firms/developers, interest groups and educational institutions. The stakeholders and the responsibilities that they undertake in decision making during the policy making, planning and implementation stages, are fundamental to the analyses of wind energy development in South Africa. Therefore, participation from all stakeholders is required, as they will compete and cooperate to attain their objectives, such as profit, market share and minimizing environmental impact, and they will also mitigate or eradicate all political, technical, economic, social, and environmental barriers. The following sections identify the major stakeholders in the South African wind energy industry, and examine their activities with respect to the present status of development in the country.

2.7.1 The Government

The South African government is the principal and most influential stakeholder in the energy sector. It plays an important role by creating an enabling environment through policies, reforms, legislations, targets, and rules and regulations for the growth of the wind energy industry. Government participation occurs at virtually all phases, including policy making, planning, permitting, licensing, financing, installation, and regulations of other stakeholders in the industry. Dulal *et al*. (2013) confirmed this by mentioning that the role played by every government is warranted in promoting the generation of renewable energy, especially when there is unwillingness from institutions and markets to change from cheap carbon fuel supplied electricity to renewable energy. The leading government departments, agencies, and authorities in the promotion and development of wind energy in South Africa include the Department of Energy (DoE), ESKOM, the National Energy Regulator (NERSA) and municipalities.

The DoE is required to explore, develop, and manage South Africa's mineral and energy resources. It is solely mandated to promote and initiate renewable energy projects and precisely monitor the quantity of energy produced from renewable energy annually. A number of programs initiated by the department towards the promotion of wind and renewable energy, includes the 70 GWh produced from various sources of renewable energy in 2004; monitoring and evaluating the White Paper's target of generating 10 000 GWh from renewable resources by 2013; originating South Africa's Wind Energy Programme (SAWEP); and the launching of the *South African Wind Energy Awareness Campaign: Powered by Wind* on December 8, 2011. This campaign was the country's first awareness campaign targeted at wind energy development. ESKOM is the national electricity provider, generating 96% of South Africa's electricity, with the remainder produced by private generators (3.2%) and municipal authorities (0.8%) (Amusa *et al*, 2009). The Wind Fleet department oversees the promotion, research and development of the country's wind energy industry.

NERSA is the regulatory authority established in terms of the National Energy Regulator Act (40 of 2004), and they function as the National Electricity Regulator as set out in the Electricity Act of 1987). The government regulates the energy industry in accordance with government laws, policies, reforms and international best practices in support of sustainable development. They regulate electricity tariffs, renewable energy incentive tariff rates, and the services provided by ESKOM. NERSA is required to set clarified and updated guidelines on net metering tariffs, record keeping, and reporting for small-scale (< 100 kW) embedded generation within municipal boundaries (Frost & Sullivan *et al*., 2013; CoCT, 2012). The municipalities or local councils are responsible for the distribution of electricity in order to make the commodity more accessible and affordable. While municipalities have great responsibilities toward the diffusion of clean energy in South Africa, their roles regarding renewable energy are undefined and not included in the IPP definition and the IRP 2010-2030 (CoCT, 2012). The ideal situation regarding wind energy development projects, however, would be that municipality authorities are required in project management, local involvement, approval, permitting, licensing, etc.

While the government had been offering support to wind and other renewable energy systems in the form of finances (subsidies, grants, and feed-in tariffs, quotas), institutionally, by setting several targets, through public consultations, through wind demonstration projects, and educational assistance. A major threat to the development of the wind market in South Africa, just like in several other countries, is the conventional electricity rates. A bulk of the nation's energy policies has been targeted at subsidizing electricity costs, which results in low electricity prices, making investments in wind energy unattractive.

2.7.2 Non-Governmental Organisations (NGOs)

These NGOs are interest organisations promoting wind energy in South Africa and they include the South Africa Wind Energy Association (SAWEA) and the South African Renewable Energy Council (SAREC). SAWEA, established in 1998, is a non-profit organisation representing the wind industry in South Africa. It is an interest organisation that promotes wind energy (small wind inclusive) in the country, and membership includes access to both national and international entities active in the entire wind energy supply chain. The association partners with governments and private entities in contributing knowledge and human resources, disseminating information, acting as a mediator for discussions between members, government, the media and the public, advocating for wind development projects, launching campaigns and creating awareness, and streamlining the policy and regulatory framework for wind energy generation in the country(SAWEA, s.a).

SAREC is another interest organisation that promote renewable energy in general, thus they also promote wind energy. The organisation was founded by four of South Africa's leading renewable energy associations. The founding members are the South African Photovoltaic Industry Association (SAPVIA), the South African Wind Energy Association (SAWEA), the South African Solar Thermal Industry Association (SASTELA) and the Sustainable Energy Society of Southern Africa (SESSA). SAREC must act as a collective custodian and voice for the development of renewable energy in South Africa, and works collectively towards optimising the regulatory and policy framework for renewable resources (SAREC, s.a).

2.7.3 Private Sector (Developers, Investors, Manufacturers)

Wind developers and contractors are investors and owners of wind farms. These stakeholders buy or lease wind sites and design, build, finance and operate wind turbines on them. The manufacturers design and produce the turbines, related components, and the software. The stakeholders in the private sector are assisting the development of the South African wind market. Table 2-3 presents the list of wind developers operating wind farm projects in South Africa.

Table 2-3: Wind farms and wind developers in South Africa

Wind Farm	Location	Capacity (MW)	Developer
Darling	Western Cape (Cape Town)	5.2	Darling Windfarm (Pty) Ltd
Klipheuwel	Western Cape (Cape Town)	3.2	ESKOM, Biothern Energy
Sere	Western Cape (Vredendal)	100	AfDB, World Bank, AFD, International Bank for Reconstruction and Development, European Investment Bank, CTF
Coega	Eastern Cape (Port Elizabeth)	45	Coega Dev Coy/ Electra winds
Jeffreys Bay	Eastern Cape (Kouga)	138	Jeffreys Bay (Pty) Ltd
Amakhala Emoyeni	Eastern Cape (Bedford)	750	Windlab
Dorper	Eastern Cape (Queenstown)	100	Rainmaker Energy Projects (Pty) Ltd
Cookhouse	Eastern Cape (Port Elizabeth)	138.6	African Clean Energy Dev

Source: Compiled by author

While existing wind development projects in South Africa have mainly concentrated on wind farms containing multiple large turbines, the country has active small and medium wind turbines and associated component manufacturers, delivering different sized turbines and various related components (that are designed and manufactured locally to a large degree) to consumers. The small wind turbine manufacturers operating in South Africa and their descriptions are presented in Table 2-4.

Table 2-4: Small wind turbine manufacturers in South Africa

Manufacturer	Description
Kestrel Renewable Energy	A subsidiary of Eveready Diversified Products (Pty) Ltd, commenced operations in 1999. It is South Africa's leading small wind turbine manufacturer and manufactures 100% locally made turbines from its base in Port Elizabeth. Operating both in the local and international markets, the firm sold approximately 600 wind turbines in 2013. They have a range of SWT rated at 0.6 W, 0.8 W, 1 kW and 3.5 kW, all of which feature robust turbine construction and unique engineering solutions. Their e400nb turbine model has been UK (MCS) and US (SWCC) certified.
Winglette Wind Machines	Based in Harrismith, they manufacture a range of *Winglette* W03 model turbines. It is a horizontal-axis wind turbine that generates 3 kW at a wind speed of 11.7 m/s. These turbines can be configured with either a stand-alone tower, or a guy wired tower; come with a battery bank and DC/AC inverter, or with a grid tie inverter without a battery set.
Adventure Power	A subsidiary of the Venture Group, and located in East London, they develop and manufacture 300 kW medium sized wind turbines for the provision of cost-effective electrical power in areas where wind speeds are conducive for wind energy generation.
Isivunguvungu Wind Energy Converter (I-WEC)	Established in 2009, and in 2011 partnered with DCD Dorbyl to manufacture local towers and blades for 2.5 MW turbines. As of 2013, DCD purchased a majority stake in I-WEC and the company has now been renamed DCD Wind Towers. DCD Wind Towers plans to manufacture towers, blades and assembles nacelles in its new facilities in Coega IDZ, in the Eastern Cape. However, for the time being, their plans to sell complete turbines are on hold pending additional investments for their business.
Palmtree Power	Located in Gauteng, their 300 kW turbines uses direct drive technology, and therefore require no gearbox. The turbines were designed to use only a few components, and do not require intermediate shafts and couplings. They have a hub height of 32 meters, and use a lattice tower, which although not as aesthetically appealing, often works out cheaper. The blades are constructed from fibreglass.
African Wind Power (AWP)	They manufacture a range of 0.5 kW to 10 kW turbines with large diameter and low RPM rotors that capture maximum energy starting in low wind speeds. The AWP 3.6 model is based on the 3.6 meter diameter rotor. The rotor is quiet and the turbine presents huge energy delivery in low and moderate winds. This machine was improved and is now the AWP 3.7 (3.7 m diameter rotor).

Source: Compiled by author from interviews and homepages

2.7.4 Research Centres and Universities

The growth of the industry requires an educated workforce to design, build, operate, maintain and advance wind energy technology. Several wind energy related educational programs are already being offered by universities and research centres across the country, as expressed in Table 2-5.

Table 2-5: Wind energy related educational programs in South Africa

School	Location	Degree/Program
South African Renewable Energy Technology Centre (SARETEC)	Cape Peninsula University of Technology, Bellville Campus, Cape Town	Wind Turbine Service Technician Training
Centre for Distributed Power and Electronic Systems (CDPES)	Cape Peninsula University of Technology, Bellville, Cape Town	MS and Ph.D. engineering programs in wind energy
DUT Energy Technology Station	Durban University of Technology, Durban	Research in wind energy
Centre for Research and Continued Engineering Development (CRCED)	North West University, Potchefstroom	MS and Ph.D. programs in energy management
Energy Research Centre (ERC)	University of Cape Town, Cape Town	MS and Ph.D. energy programs in wind energy
Centre for New Energy Systems (CNES)	University of Pretoria, Pretoria	MS and Ph.D. programs in wind energy
Sustainable Energy Technology Testing and Research Centre	University of Johannesburg, Johannesburg	Research in sustainable energy
Centre for Renewable and Sustainable Energy Studies (CRSES)	Stellenbosch University, Stellenbosch	Postgraduate Degree in renewable and sustainable energy
Future Electrical Energy Technology (FEET)	University of Witwatersrand, Johannesburg	Research in wind energy

Source: Compiled by the author from related homepages.

Similarly, the government operates a state owned research institute, the South African National Energy Development Institute (SANEDI), established as a successor to the previous South African National Energy Research Institute (SANERI) and National Energy Efficiency Agency (NEEA). SANEDI is required to promote, conduct, and monitor applied energy research and development, and deploy wind and other renewable energies and promote energy efficiency in South Africa.

2.8 Path to Technological Development

The rise of new and emerging technologies and their impacts and applications in revolutionising society have a lengthy history. Their potential in tackling social, economic, environmental, health, agricultural, and energy issues are enormous. The advancement of these technologies has a vital role to play in attaining the objectives of the UN Convention on Climate Change and environmental sustainability. Today, governments view developments in novel science and technology as essential in maintaining competitive positions in the world (Mehta, 2002). The technological change and innovation potential connected to novell technologies serve as an essential driver of economic growth (Kowalczyk, 2013; Dosi, 1982; Nelson & Winter, 1977).

The technological life cycle can be divided into different phases, namely: formation, growth and saturation (Grubler, 1997; Sanden, 2004). The first phase, the formative phase, is characterised by uncertainty. The market diffusion of emerging technologies is often slow, since costs are high and performance often inferior to the performance of existing technologies. In addition, the emerging technology may not fit into the technical, institutional and social make-up that have evolved around the entrenched technology (Frankel, 1955; Dosi, 1982; Nelson & Winter, 1982). Following an initial diffusion on market niches (that may or may not be protected), the new technology may gain momentum (Kemp *et al*., 1998). In the growth phase, a number of positive feedback mechanisms, or positive returns to adoption, set in motion a process that leads to a more rapid diffusion. Once established, the position of the dominant design is further re-enforced by moulding the surrounding technical, institutional and behavioural environment through additional lock-in mechanisms (Sanden, 2004).

A significant aspect of the successful development of a technology is the embedding of the new technology in a society (Kowalczyk, 2013). Moreover, in this age of high investment projects, decision makers are interested in the early identification of promising directions and options for technological emergence so as to choose the 'right' development path (Kowalczyk, 2013). Development is generally termed as an improvement, either in the general situation of a system or in some of its constituent elements. It is a multi-dimensional concept, as any improvement of complex systems can occur in different ways, at different speeds, and driven by different forces (Bellu, 2011). Countries and the international development communities have privileged specific ways of achieving development at different periods, adhering to a defined modality or path to achieve development, based on a codified set of activities and/or based on a vision regarding the functioning and evolution of a system (Bellu, 2011).

There is a rationale in innovation studies that technological development and innovation processes are complex, non-linear, multi-actor and multi-level processes (Nelson & Winter, 1977; Smits *et al.*, 2008; Kowalczyk, 2013). Societies, scientists, planners and decision-makers are required to determine the current status of technology and anticipate future events (Kowalczyk, 2013). In a technological field, the various actors have an impact on technological development through their actions and interactions. These actors, which include governments, non-governmental organisations (NGOs), private sectors, and academic and research institutions, have different responsibilities – scientists work in research groups, governments make policies, NGOs are interest groups, private sectors make investments – hence, the technological development and innovation processes are viewed as outcomes derived from the many interactions and feedbacks between these actors (Kowalczyk, 2013).

The actions and interactions of actors in a technological field underscore the rationale that technological development is socially built. According to Bijker *et al*. (1987) and Kowalczyk (2013), technology and society mutually impact on each other and co-evolve. Technological fields are regarded as socio-technical worlds, where actors built networks that are based on shared expectations, visions, cultures, shared beliefs and agendas (Garud & Rappa, 1994; Kowalczyk, 2013). It can be inferred that both technology and society are requisites for consideration when studying technology emergence and development. Therefore, the formation of strategy and policy that guide technological development into sustainable paths is a great challenge (Sanden, 2004).

Path creation and path dependency are fundamental theories of technological development (David, 1985; Arthur, 1988; Kowalczyk, 2013). These authors infer that technological development is a product of the past and present actions and structures. Furthermore, there can be a deviance from these actions and structures to develop new technology paths. The concept of paths, which demonstrate that technological development follows a certain direction, was presented by these theories. As the actors act, interact, position themselves, take decisions, etc., certain patterns begin to occur, thus resulting in linkages, alignments and networks (Van Merkerk & Robison, 2006).

These patterns are important for the stabilisation process of technologies, have an enabling effect on technological field development, and are the point of departure for new technological paths and the basis for understanding the dynamics of emerging technologies (Kowalczyk, 2013).

Collingridge (1980) expressed that it is hard to manage emerging technologies (Kowalczyk, 2013). The early phase of an emerging technological field is usually characterised by several unorganised and organised activities. Initially, technological development is rather fluid and open, many technical options are abound, multiple development paths are possible, variation is high, and predicting the future impact is rather difficult (Kowalczyk, 2013). However, as time passes and the technology becomes more developed, certain options and directions become more promising and accepted than others, therefore, the paths to the future become more visible and rooted. The process of variation and selection is one of the basic mechanisms underlying technological developments, as these mechanisms result in the forming of technological development pathways (Nelson & Winter, 1977).

Emerging technologies are future oriented and are mainly made up of expectations and visions, and the further development of the technologies is dependent and influenced by the expectations and visions of relevant actors (Van Merkerk & Van Lente, 2005; Brown & Michael, 2003). Expectations, agendas and networks are the building blocks of the patterns and technological paths in a science and technological field (Brown & Michael, 2003; Borup *et al*., 2006; Kowalczyk, 2013).

Expectations are defined as real time representations of future technological situations and capabilities, and they are used as a guiding structure in emerging fields as they guide activities and influence the agenda setting (Borup *et al*., 2006). In the emergence of the technological field, expectations attract resources, reduce risk, gain visibility, create legitimacy and guide activities, align actors, and inform strategies (Brown & Michael, 2003; Borup *et al*., 2006; Geels, 2007; Van Lente *et al*., 2013). When more expectations become shared they start to form a visible development pathway for the new technology (Van Merkerk & Robinson, 2006). Expectations have the power to influence development, i.e. they contain a script which is used to attract the interest of various actors in the innovation network. The interest of actors can be transformed into an agenda. Agendas are lists of priorities which are to be executed and thus require action. Actions which result from the agenda setting processes create new networks between relevant actors, and thus shape the structure of an emerging field (Van Lente *et al*., 2013; Kowalczyk, 2013). Furthermore, expectations change over time as they respond to new conditions, findings and problems (Borup *et al*., 2006). The actors involved in the setting up of the expectations, agenda and networks are located in scientific research communities, governmental programs and the private sector (Van Merkerk & Robinson, 2006).

Technology path assessment deals with the questions: What is happening now? Where do we want to go? Why do we want to go there? And, how can the current development be linked to future desirable outcomes? (Sanden, 2004). According to Bellu (2011), it is important to assess past processes and design andredesign ongoing/future ones in order to find new perspectives for development processes and related policies. Through the actions and interactions of different actors in government, non-governmental sector, private sector, and academia, a development path for small wind technologies in South Africa is expected to be formulated. This path formulation will rely on the building blocks of a technological development path that consist of expectations, an agenda, and networks. The theory of technological development for new and emerging technologies is made applicable to this research. The small wind energy system is an emerging and promising technology for generating electricity, hence, the theoretical framework of this research work is guided by the diffusion of innovation theory.

2.9 Conclusion

The literature review indicated a small wind sector that is gradually and consistently developing worldwide. The installed capacity of small wind turbines is increasing, supplying electricity to isolated consumers, grid-connected households and others. The small wind energy system is a matured technology that has been in existence for several decades, originally receiving acceptance in the early 20th century among small farmers and ranchers. The systems provide clean, renewable power for on-site applications and reduce the burden on the power grid, while providing energy security for households, businesses, communities, farms, and public facilities in the developed and developing world. More recent studies are focused on improving the designs of these systems and their power capture.

Although economics and the environment are still principal concerns, the demand for the system is still being motivated by a combination of economics, practicability, and values. While small wind energy have environmental benefits over fossil fuel generations, some possible environmental and health concerns associated with small wind installations still exist, and they include visual impact, noise, avian mortality, and electromagnetic induction (EMI). However, these concerns are largely considered to be manageable and do not pose a major threat (Kwartin *et al*., 2008).

Despite the fact that the small wind sector is still at infancy in South Africa, the study revealed that South Africa is a country with abundant wind resources, available policies, ambitious targets, committed stakeholders, technologically-experienced firms, knowledge-based research centres and universities. Currently, small wind turbines and components are mainly locally designed and manufactured out of local material, and the market potential is huge. Unfortunately the policy programs are designed and targeted at large scale wind generation, with almost no policies in place for small-scale generation like small wind energy systems. The relative lack of research literature on the nation's small wind sector is also apparent. South Africa's dominance in small wind power production in Africa is both feasible and sustainable. In defining the development path to viability and future growth of the sector in the country, the next chapter discusses the research design and methodology.

CHAPTER 3
RESEARCH DESIGN AND METHODOLOGY

3.1 Introduction

This chapter describes the methodology adopted by the study. The research work and its findings were both a combination of qualitative and quantitative methods to develop internally consistent storylines assessed through quantifications, which are then discussed in a narrative form (Alcamo *et al*., 2005). The methodology for the research study comprised of comparative case studies and it also examined the support policies of small wind sectors (at different developmental phases) in selected countries and the performance of the small wind technology in selected locations in South Africa. The research aimed to evaluate the effects of the available policies benefitting small wind energy systems and the technology performance of these systems on the viability and future growth of this sector in South Africa, and propose an alternative development path to overcome the limitations.

Firstly, this chapter justifies the research methodology, followed by a description of the experimental design, data collection and methodology verification, research ethics, and research validation. The development path for small wind energy systems will provide policymakers, investors, manufacturers, distributors, and academics with information for effective policy design, better investment and improved technology performance.

3.2 Justification of the Methodology

Given the dearth of reporting on small wind generation in South Africa, and the subjectivity of the subject matter, there arises the need to initially develop an in-depth understanding of the subject matter, hence the application of qualitative methodology, and particularly, case study approach. However, considering the study requires the quantification of some indices such as wind speed distributions, energy yield, cost of energy, economic performance, etc., a combination of qualitative and quantitative methodologies was justified. Eisenhardt (1989) expressed that a great synergy occurs when qualitative and quantitative data are combined in a research study.

The case study is a research approach that concentrates on understanding the dynamics available within single settings (Eisenhardt, 1989). It entails considering an example or occurrence (a case) for study or research (Ticehurst and Veal, 2000; Finlay-Jones, 2007), and the case being considered for analysis in this study is the development of small wind sector. Firstly, the support policies for the small wind sectors of two selected developed countries were studied and compared to that of South Africa. Secondly, the technology performance of small wind energy systems in twelve selected geographical locations in South Africa was studied. Furthermore, the adoption of the exploratory case study approach for the small wind sector (Yin, 1994; Ticehurst & Veal, 2000) demands that suitable cases cover varied locations, weather conditions, countries, policies, and turbine models.

3.3 Experimental Design

In this thesis, the data collection and analysis for further development of the small wind sector in South Africa involved an extensive review of the literature, interviews with stakeholders, and qualitative and quantitative approach to analyse the data collected. Although the research design for a study can be historical, survey descriptive or inferential, or pure experimental, the research design for this study is both survey descriptive and pure experimental (Van Dalen, 1979; Nenty, 2009). Survey descriptive, as it was used to describe or determine *'what* is' the effect or impact. While the part of the design that was pure experimental, attempted to determine '*what will or what could be'* when the variables are varied against each other under a controlled condition.

3.3.1 Data Collection

The data collection for the research study involved an extensive review of literature and interviews with related stakeholders. The process for collecting the needed and relevant data required first, the collection of existing and available data largely through document reviews. Afterwards, new data were generated through primary research, which involved qualitative expert interviews.

Document Review

The document review for data collection was an iterative process performed continuously during the research, which produced an analytical framework that guided the study. It involved a broad review of energy journals, legislative acts, doctoral theses, academic publications, policy documents, and government funded research reports in South Africa and beyond. A review of previous and on-going research on all topics relating to small wind generation was undertaken to collect information, and both local and international literature were considered in order to have improved knowledge, compare, modify data and models, and infer on small wind turbine operations, policies, markets, technologies, and projects across the globe.

Stakeholders Interview

The focus here is on expert interviews, laden with exploratory conversations. The interviews were consultative processes used for data collection and sought the direct participation of stakeholders in the wind and related industries. Swart *et al*. (2004) termed stakeholders as the organisations that can have a significant limiting or accelerating influence on the project implementation. The interviews consisted of a mixture of two types of questions: semi-structured and structured questionnaires (Mintrom, 2003). This allowed for in-depth qualitative and quantitative data collection. The semi-structured interview contained open-ended questions that brought about broad discussions on small wind energy systems. The interview questions/questionnaire is presented in Appendix D.

The various research interview participants were selected through contacts within the wind and energy-related industries, referrals from other interviewees, energy literature, reports, public documents, and online searches. The participants were contacted via phone calls or email and requested to be part of the research project. Afterwards, a series of interviews were conducted to understand the needs of the participants and their industries and obtain their input on further development of the small wind sector in the country. Purposive sampling was used for the selection of the interviewees as this ensured that the most appropriate stakeholders were consulted. Furthermore, diversification was applied in the selection process, with interviewees selected from many sectors and provinces so as to have access to a wide range of concerns and responses. The research study reflected on inputs from over 20 stakeholders related to the wind and energy industry, and these stakeholders included individuals in government agencies, departments and municipals, associations, universities, developers, utility, wind turbine manufacturers, businesses and end-users in the country. The list of stakeholders consulted is presented in Appendix E.

The mode of interview was largely face-to-face and Skype video, supported by telephone and email correspondence that produced new data and equally confirmed and discussed research findings. The interviews were recorded and transcribed afterward to facilitate a detailed analysis. The respondents were allowed to tell their own stories, and when necessary, the interviewer had to probe the respondents further with supplementary questions to obtain the needed data and information. Subsequently, all the text material from the interviews and the document reviews were structured and sorted methodically, and further analysed.

3.3.2 Policy Analysis

Most policies supporting renewable energy have multifaceted objectives, including removing market barriers, diversifying state and national energy portfolios, improving human health and the environment, securing long-term energy supplies, and provide new energy development opportunities (REN21, 2009). These policies must purposely deliver attractive investment conditions for new market entrants in the whole value chain for a wide range of technologies, and the policies must also support high-risk innovative entrepreneurship (Jacobsson *et al.*, 2009; Ross *et al*., 2012).

The objective of the policy analysis is to evaluate the available policies benefitting the small wind sector; the specific factors that determine these policies in terms of return and risks measures; and their effects on the viability and further growth of the sector. The market growth or diffusion of renewable technologies can be measured by various indices, namely: installed capacity, energy generated, number of established renewable energy businesses or jobs created, performance measurement, etc. (Gouchoe *et al*., 2002; Luthi, 2011).

The case study approach was used for the evaluation of the available policies. The case study approach is a type of empirical research in which a contemporary phenomenon is studied in its real life context. The boundaries of the phenomenon of the case studied and the context are not clear and evident, and in the case study a number of sources of information are used (Yin, 1994). This case study research design involved comparing the support policies benefitting the small wind market in South Africa with that of the US and the UK (countries with developed small wind markets). According to Whale *et al*. (2013), the growth of the global market for SWTs has been remarkable, predominantly in the US and the UK. The available information on these two markets forms the benchmarks for this study. Each market study focuses on the policy, its effect on installed capacity, and the reactions and feedbacks from government agencies, turbine manufacturers, end-users, and other stakeholders. As recent data were not readily available, publicly available data were complemented with professional interviews.

The diffusion of innovation theory provided the theoretical framework for the policy evaluation of the case studies, and it stimulated the role of policy-makers as key actors in the diffusion process. The technological life cycle, as discussed in the path to technology development, was used to demonstrate the development of the small wind market. According to Grubler (1997) and Sanden (2004), the diffusion of technologies is inclined to form an S-shaped curve (discussed further in chapter 4). In applying their terminology, small wind systems development can be divided into three phases, namely: formation, growth and saturation. These selected case studies were structured to the different phases of market development with regard to the diffusion theory framework, and evaluated.

After structuring, a return-risk measure was used for the evaluation of the case studies (Luthi, 2011). As explained by Luthi (2011), making decisions for renewable energy project development is influenced by several factors, which can be divided largely into risk and returns factors, and some of these factors can be influenced by policy-makers. These particular factors (illustrated in Figure 3.1) include all kinds of government action concerning renewable energy policies (Butler & Joaquin, 1998).

The return factors are elements that positively influence the returns on a small wind project investment, and they include:

- Level of incentives: *How high is the financial support?*
- Duration of incentives: *How many years is the support guaranteed*?
- Wind resource: *How abundant*?

The risk factors represent usual policy risks for investors, and may constitute a negative influence on the (expected) return on investment. These factors include:

- Policy stability: *Any major, unexpected policy changes in the past? Etc.*
- Cap: *Limit on the amount of small wind electricity to be supported under FIT? etc.*
- Administrative process: *How many permissions are required? How many authorities are involved? How long does the administrative process take?*

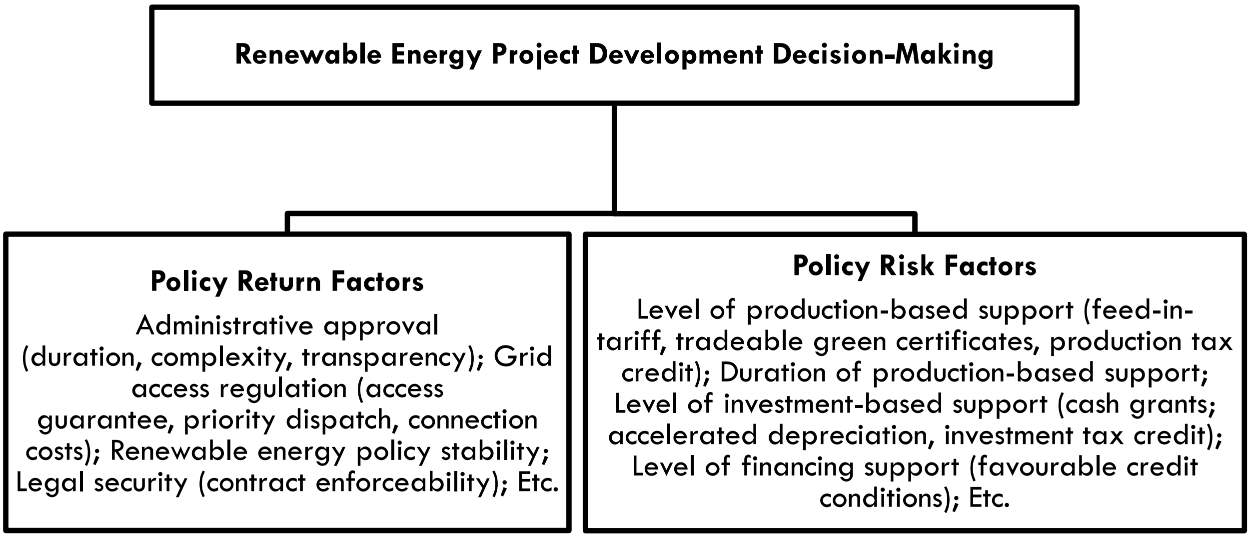

Figure 3-1: Factors influencing decision-making for RE project development (not exhaustive) (Adapted from Luthi, 2011)

3.3.3 Technology Performance Analysis

While incentives are needed to facilitate the growth of renewable energy, the successful application of such programs requires the evaluation and provision of information on the energy performance, economic viability, and environmental benefits of the systems for informed policy development to regulate the renewable energy market (Luthi, 2011). The objective in this section of the thesis is to evaluate the technology performance of small wind turbines in the country and how it affects the viability and further growth of the sector in South Africa. The evaluation of the technology performance involved examining the techno-economic performance (i.e. energy productivity and economic viability) of small wind energy systems in different geographic locations of the country.

For the purpose of the thesis, the country was divided into four different regions due to the variation in the wind resources of the country and the large expanse of the geographic area. The four regions are the Cape Peninsula, the South-Eastern, Central, and Northern regions (Kruger *et al*., 2010). Three locations in each region were considered for evaluation, totalling the investigation of twelve locations. The Cape Peninsula region included Cape Town, Oudtshoorn, and Worcester, while the South Eastern region consisted of Port Elizabeth, Grahamstown, and Richards Bay. The Central region comprised of De Aar, Bethlehem, and Potchefstroom, while Johannesburg, Nelspruit, and Polokwane were considered for the Northern region.

The wind speed data of all the locations were collected from the South Africa Weather Service (SAWS) to determine the wind characteristics and probability distributions of the locations using the Weibull distribution function, a mathematical model for analysing local wind load probabilities (Lun & Lam, 2000; Gupta & Biswas, 2010; Ayodele *et al*., 2012b). The average wind speed data were measured at an hour interval over a period of 5 years (2010 — 2014) at a height of 10 m above ground level (AGL).

Thereafter, the amount of energy that could be produced by a small wind system in each site location was computed. Two commercially available small wind turbines (SWTs) were evaluated for each site. They are the e300i (1 kW) and the e400n (3.5 kW) models manufactured by Kestrel Renewable Energy. The energy outputs of the selected turbines at all the sites were calculated by combining the wind probability distribution of each site with the power curves of the selected turbines (Burton *et al*., 2001; Gokcek & Genc, 2009).

The economic performance of the two selected SWTs was evaluated for all the sites. The accurate evaluation of the economic feasibility of small-scale generation technologies is important, because it allows an end-user to measure the total expenditure and the system's payback period (Gagliano *et al*., 2013). Basic economic models for evaluating the electricity generating systems were used for the economic evaluation, and they include: Simple Payback Period (SPP); Net Present Value (NPV); and Levelised Cost of Energy (LCOE), in order to provide a balanced representation (Bishop & Amaratunga, 2008; Ayompe, 2011; Simic *et al*., 2013). Furthermore, the environmental value discussed influences the external cost concept. The costs estimated for the selected turbines in the different sites in the economic analysis, never took the environmental impact into consideration, but this is very important when making comparison with fossil fuel generation.

3.3.4 Hypothesis Testing

Hypotheses are formal conditional statements describing the expected relationship between two or more dependent and independent research variables (Creswell, 1994; Prasad *et al*., 2001). They can be tested by argumentation, and logically justified by demonstrating that they are conclusions of appropriate arguments (Giere, 1984). Zarefsky (2014) expressed that argumentation forms a rhetorical analogue to hypothesis testing in the scientific methodology, and should be used to determine the truth in circumstances where empirical methods are unobtainable.

Arguments are a set of statements (propositions) that can be divided into two groups – premise and conclusion, where the premises are the statements upon which the conclusions are drawn (Giere, 1984). Giere (1984) further argued that, in a strong inductive argument, the premises support the conclusion in such a way that, if there is an assumption that the premise is true, then, based on that assumption, the conclusion is probably true. Such an argument employs particular cases to reach general principles. However, the "probably true" premise does not indicate that the truth value of the proposition is eternal and unchanging, but that, under the present situation, the proposition can be allowed (Zarefsky, 2014). According to Giere (1984), two conditions are required to justify the conclusion: the premises must be justified; and adequate connections must be established between the premises and the conclusions. And Giere's (1984) three criteria for judging these connections are: prediction is deducible from the hypothesis and the initial conditions; prediction is improbable when not considered in the context of the hypothesis; and prediction is verifiable.

The hypothesis testing for this research study is through argumentation. The research hypotheses for this thesis comprised two independent variables (policy and technology performance) and one dependent variable (viability and future growth). The alternative (H_1) and null (H_0) hypotheses tested and verified by this study are:

Alternative Hypothesis H_1

The viability and future growth of the small wind sector in South Africa is limited by the presently available policies benefitting the systems and technology performance, and therefore requires a sustaining alternative development path to overcome the limitations.

Null Hypothesis H_0

The viability and future growth of the small wind sector in South Africa is not limited by the presently available policies benefitting the systems and technology performance, and therefore a sustaining alternative development path to overcome the limitations is not required.

In the process of testing these hypotheses, sub-hypotheses were further derived from the main hypotheses, where the dependent variable (viability and future growth) was varied against each independent variable (policy and technology performance), thereby, forming relationships between the variables as expressed in the matrix below.

Sub-hypotheses

- Policy

  H_1: The viability and future growth of the small wind sector in South Africa is limited by the presently available policies benefitting the systems.

  H_0: The viability and future growth of the small wind sector in South Africa is not limited by the presently available policies benefitting the systems.

- Technology Performance

  H_1: The viability and future growth of the small wind sector in South Africa is limited by the technology performance of the systems.

  H_0: The viability and future growth of the small wind sector in South Africa is not limited by the technology performance of the systems.

In testing and verifying the policy sub-hypotheses, the two conditions proposed by Giere (1984) were applied. The premises from which the conclusions were drawn were justified and the connection between the premises and conclusions were adequately established, using the case studies of three different small wind markets with different levels of development and deployment. The available support policies for the different small wind markets selected for study were thoroughly analysed with the support of: academic publications, policy documents, government funded research reports, and other related doctoral theses; and valuable contributions from related experts. The conclusions arrived at in the thesis for the alternative sub-hypothesis (policy) H_1, were supported by the premises (results from the analysis) such that, the assumed premise is true, thus, making the conclusion to be probably true, based on that assumption.

Similarly, the test and verification of the technology performance sub-hypotheses witnessed the justification of the premises of the study and the adequate establishment of the connection between the premises and conclusions drawn, using different geographical locations in the country and two differently rated small wind turbines as cases. The two different turbine models were quantitatively analysed in twelve different settings for energy productivity and economic performance. The conclusions reached in the study for the alternative sub-hypothesis (technology performance) H_1, were supported by the premises (results from the analysis) such that, the assumed premise is true, thus, making the conclusion to be probably true.

Overall, the success criteria for the two alternative sub-hypotheses of this study were met and supported, thus, the *Alternative Hypothesis* H_1 was fulfilled that, the viability and future growth of the small wind sector in South Africa is limited by the presently available policies benefitting the systems and technology performance, and therefore requires a sustainable alternative development path to overcome the limitations.

3.3.5 Development Path Formulation

The building process for the development path involved the definitions of the problem statement, research aim and objectives, thesis statement and hypotheses, and the activities for these definitions include reviewing literature, observations, discussions with experts and colleagues, and gathering and processing data. After the various evaluations, findings, and subsequent testing and verification of the two sub-hypotheses, the main hypotheses were equally tested and verified. The tests for the main hypotheses involved proving all the research results and verifications of the two sub-hypotheses against the main hypotheses to verify their fulfilment. Afterward, approaches were taken to define and propose a sustaining alternative development path for the sector to overcome the limitations identified. These approaches and activities involved the complexity of diverse issues with various stakeholder participations and an extensive review of literature, and described how related stakeholders of the sector should address the viability and sustainable growth of the systems in the country.

The activities included the proposition of two development paths termed the advanced-growth and moderate-growth path. The advanced-growth development path is designed as a near-term temporary solution, incentive-driven, and built on the assumption that the continuous provision of market-pull support policies for the sector in South Africa will address the limitation posed by high up-front cost, which is the major biggest threat mostly to small wind deployment, and quickly grow the market. The moderate-growth development path seeks a reduced level of political interference, and is a cost-competitive and long-term sustainable solution where the system needs to rely on improving its economic performance so as not to be needy of market-pull incentives supports for sustenance in the future, but technology push policies.

3.4 Data and Methodology Verification

Morse *et al*. (2002) suggested that a researcher should focus on the processes of verification during a study, rather than focusing on strategies to establish trustworthiness at the end of the study. Focusing more on the establishment of trustworthiness can lead to the risk of missing severe threats to the reliability and validity, until it will be too late. In ensuring this does not happen, the research processes used in this study were verified. Verification in a qualitative research study can be termed as the mechanisms applied during a research process to increasingly contribute to guaranteeing reliability and validity of the study (Morse *et al*., 2002). These mechanisms simply make certain, ensure, confirm, and check. Furthermore, these mechanisms are knitted into all the phases of the research to build a formidable product (Kvale, 1989; Creswell, 1997) to ensure that errors are identified and rectified in order to prevent them from being assembled into the developing model and consequent subversion of the whole analysis. Thus, a worthy researcher goes back and forth between the research design and execution, making certain there is alignment between question formulation, literature, data collection, and analysis. These research actions entail checking data methodically, sustaining focus, and continually monitoring and confirming the analysis concept and interpretation (Morse *et al*., 2002).

The verification of this study involved the application of the five verification approaches to ensure reliability and validity of the study articulated by Morse *et al*. (2002). These approaches guide the researcher in ascertaining when there is need for continuation, stoppage or modification of the research process to ensure a reliable and valid outcome, and they are:

3.4.1 Methodological Coherence

In obtaining methodological coherence in research the researcher must ensure that congruence exist between the research question and the units of the method being applied. Morse *et al*. (2002) expressed that, the interdependence of qualitative research requires that the question being asked links with the method being used to provide answers to this question, which in turn links with the data collected and the analytical processes. While a researcher may lean towards a positivist, post-positivist, interpretivist, constructivist, postmodernist, poststructuralist, or pragmatic philosophical beliefs regarding research practice and conducts reflective, descriptive, critical, or evaluative research, a unified or methodologically coherent research structure must be produced. In this research process all the "pieces" must fit together and share the same foundational beliefs (DeForge & Shaw, 2012; Davis, 2012).

The different research methods and models adopted for the qualitative and quantitative approaches of this study are very well established and suited for this specific research. A major research method applied in this study was the case study. According to Yin (1994), a case study approach is applicable to research when: *a how or why question is being asked about a contemporary set of events over which the investigator has little or no control*. The central questions of this thesis were: *how two developmental variables, policy and technology performance, affect the viability and further growth of the small wind sector and how to realise further development.* These questions justify the use of the case study approach, and importantly, this approach can ensure and certify coherence (congruence) between the questions and the methodology applied. Perry *et al*. (1999) provide four reasons for the application of the case study approach in this research. Firstly, this approach offers primary theories for specific phenomena by comparing and analysing similarities and dissimilarities between cases. This comparison and analysis were applied to the different policies, technology performance, location, and countries. In the second place, the case study provides an opportunity to understand phenomena. In this research more knowledge of the issues affecting the development of the small wind sector was unravelled. Thirdly, cases can be categorised and the relationship between the categories determined. In this study the selected small wind sectors were categorised into different levels of development, etc. In the fourth place, the case study approach has the capacity to be exploratory and confirmatory/dis-confirmatory at the same time.

Furthermore, the study of the results obtained in previous comparable studies that addressed similar issues in order to assess congruency is of invaluable assistance in ensuring the credibility of the methods and models for this study (Silverman, 2000). The risk-return approach adopted in the case study methodology for the evaluation of the available policies benefitting small wind energy systems in South Africa, has been successfully applied to several studies relating to the policy analysis of climate change, electricity generation, and renewable technology (Butler & Joaquin, 1998; Blyth *et al*., 2007; Gross *et al*., 2010; Luthi, 2011). Similarly, the mathematical models applied in the quantitative analysis and in computing various results in this study are well established methods used in similar studies. These models include: wind distribution functions (Lun & Lam, 2000; Weisser, 2003; Gupta & Biswas, 2010; Oyedepo *et al*., 2012; Ani *et al*., 2013; Gagliano, 2013); annual energy productions (Burton *et al*., 2001; Polinder *et al*., 2006; Chang & Tu, 2007; Gokcek & Genc, 2009; Oyedepo *et al*., 2012; Ayodele *et al*., 2012b; Shawon *et al*., 2013; Ani *et al*., 2013; Gagliano, 2013; Mostafaeipour, 2013); economic viability (Kaltschmitt, 2007; Bishop & Amaratunga, 2008; Gokcek & Genc, 2009; Ayompe, 2011; De Oliveira *et al*., 2011; Costa Rocha *et al*., 2012; Simic *et al*., 2013; Shawon *et al*., 2013; Mostafaeipour, 2013); installed capacity growth projections (Ayompe, 2011; Greenpeace & EPIA, 2011; Gsanger & Pitteloud, 2014); and learning curve for cost projections (Nemet, 2006; Winkler *et al*., 2009; Ferioli *et al*., 2009; Nemet & Husmann, 2012).

Through applying methodological coherence a solid understanding and coherence of the research structure (the research statement/questions, literature, methodologies or design, intentions, hypotheses, concerns, data collection and analysis, and inference, conclusions) was ensured. All the methods applied in this study are properly referenced. Careful and continued deliberation of the assumptions made through all phases of the research process was ensured to realise fitting of all phases.

3.4.2 Sampling Sufficiency

Sampling needs to be appropriate in a research study. It requires the inclusion of cases or participants that provide the best representation or possess requisite knowledge of the research topic (Morse *et al*., 2002), as this guarantees efficient and effective saturation of categories, with optimum valuable data and minimum unwanted data and wasted time. Sampling sufficiency signifies the collection of adequate data that will account for all the features of the case being studied, and this is demonstrated by saturation and replication (Morse, 1991). Furthermore, seeking negative cases is important and it provides validity, as it specifies parts of the developing analysis that are originally less than obvious (Morse *et al*., 2002). The saturation of data bring about replication in categories, with replication verifying and ensuring comprehension and completeness.

This study incorporated multiple cases that ensured sampling sufficiency and replication. Generally, case study research is based on multiple cases so as to realise replication (Carson *et al*., 2001). Sufficiency was achieved in the sampling of the cases for the policy and technology performance evaluation, as the widely accepted minimum range of cases is between 2 and 4, and the maximum between 10 and 15 (Carson *et al*., 2001). Apart from this, purposeful sampling as opposed to random sampling was used for the case selection in this study (Patton, 1990; Perry, 2001), which entails using replication logic instead of sampling logic. This sampling approach is utilised in order to either produce: similar results for predictable reasons, i.e. *literal replication*; or contrary results for predictable reasons, i.e. *theoretical replication* (Yin, 1994). The selection of two similar cases of developed small wind sector markets as opposed to the small wind sector in South Africa for policy evaluation, and the regional categorisation of locations with similar weather conditions for technology performance evaluation so as to achieve similar and contrary outcomes for predictable reasons ensured replication in the study. The sampling process must aim to achieve accurate statistical evidence on the variables' distribution within the population (Eisenhardt, 1989).

The sampling for this research ensured that stakeholders who best represent the industry, with adequate knowledge of the research subject were included. Sufficiency was realised, with the study reflecting contributions from more than 20 stakeholders associated with the industry. Creswell (1997) and Green and Thorogood (2009) suggested a range of between 20 and 30 participants or above in their interview studies. Purposive sampling was equally utilised in selecting the organisation to be interviewed, ensuring the consultation of the most appropriate stakeholders. Apart from articles, reports, public documents, and online searches that were used to select interview participants, respondents were asked during interviews to identify relevant actors in the industry and also to give referrals, as this ensured that important actors directly related to the value chain were not missed (Nilsson & Noren, 2011). Furthermore, consideration was given to diversification during participant selection, as respondents were selected from many sectors and provinces in order to be accessible to a wide range of concerns and responses. The researcher ensured that new respondents were continually included in this research until the data were adequate and replicated, thus ensuring the saturation of data. This ultimately increased the scope, sufficiency, and appropriateness of the data (Morse *et al*., 2002).

3.4.3 Concurrent Data Collection and Analysis

The collection and analysis of data concurrently allows for a mutual relationship between the known information and what needs to be known, and further results to realising reliability and validity (Morse *et al*., 2002). Data analysis is required to occur concurrently with the collection of data, as it encompasses a continuing process of 'testing the fit' between the data collected and the analysis (Green *et al*., 2007).

During this study, the researcher applied iterative interaction between data collection and analysis throughout the research process in order to check data, balance facts and incorporate updates to produce reliable results. Data were collected and integrated concurrently during the analysis and interpretation phase. For this thesis both quantitative and qualitative data were collected simultaneously, which enabled a broader perspective, and provided the opportunity to address different research questions and gather data and information from different groups (Terrell, 2012). Overlapping of data collection and analysis and the use of flexible and opportunistic data collection (Eisenhardt 1989) were encouraged and ensured in this study, as this will allow for adjustments during the process of collecting the data. Similarly, within-case and cross-case analysis (Carson *et al*., 2001) were regularly carried out for all the cases selected in this study in order to become familiar with data and generate a preliminary theory. Data are generally analysed in a cross-case analysis by applying content analysis of the transcripts, and coding of words and phrases into categories. The coding enables words and phrases to be identified, extracted, and clustered into concepts and themes (Miles & Huberman, 1994).

Additionally, triangulation was ensured in the study through the use of different methods for data collection and a broad range of respondents. Each of the respondent's viewpoints and experiences was verified against the others. The study recruited participants for the interviews from both the end-users of the system and the professionals that deliver, manage, or regulate it. Strategies were put in place to ensure all respondents exhibit honesty when supplying data for the study. Hence, respondents were enabled and encouraged to contribute ideas and share their experiences without fear. Furthermore, a variety of documents from reliable sources such as the South African Weather Service (SAWS), Kestrel Renewables, etc., were utilised as source material and referenced.

3.4.4 Thinking Theoretically

By thinking theoretically, ideas that emerged from the data were reconfirmed into new data, thus, leading to new ideas that must be verified by the data already collected (Morse *et al*., 2002). Theoretical thinking demands macro-micro perspectives, making steady progress without cognitive leaps, continual checking and rechecking, and the establishment of a firm foundation.

Theoretical comparison is a major device used in this research to stimulate thinking. It is a device which stimulates thinking through the properties and dimension of concepts (Corbin & Strauss, 2015), and it aims to sensitise researchers to be able to determine what to look out for in the data or to suggest ideas for theoretical sampling. In applying this device to this research, the researcher was able to derive concepts from the data, therefore the researcher was working with a concept and not the case provided in the data. Both close-in (similar type of situations) and far-out comparisons (appears different on the surface, but similar in concept) were used in the theoretical thinking of this study. Theoretical comparison helped this researcher: to progress from describing the particulars of a case to thinking more abstractly; sensitised him about likely, but unclear properties present in data; and enabled him to re-examine results and re-analyse; leading to the qualifications and alterations of the initial interpretations of a few cases in this study.

Similarly, a combined deductive-inductive approach was utilised to this study (Parkhe, 1993; Miles & Huberman, 1994; Nair & Riege, 1995). In applying this approach, prior theory (Yin, 1989) was constructed using the researcher's prior knowledge and experience on the subject matter, discussions with other related researchers, and literature. The debriefing sessions between the researcher and the supervisor helped greatly in thinking theoretically, as the experience and opinions of the supervisor broadened the researcher's ideas, visions and interpretations, and alternative approaches were discussed. The supervisor also pointed out faults in the course of action proposed, and suggested the development of improved explanations or arguments of the research design and the whole work in general. Likewise, the peer scrutiny of the study by colleagues and academics provided opportunities for feedbacks, fresh viewpoints, and challenges to the initial assumptions of the researcher. Comparisons were made between the research and related and differing literature, thus, increasing the theoretical level and instituting internal validity for the thesis. Carson *et al*. (2001) expressed that, a combination of the inductive and deductive approach is possible through: early stage convergent interviews in the course of the literature review; trials to perfect the interview procedure before the actual collection of the data; and application of open unstructured questions in starting the interview process.

3.4.5 Theory Development

Theory development involves moving with deliberation between a micro perspective of the data and a macro conceptual/theoretical understanding (Morse *et al*., 2002), and this development of theory in research occurs through two mechanisms: as an outcome of the research process, and not a framework for moving the analysis along; and as a template for making comparisons between and for further development of the theory. Theories become valid when they are logical, well-developed, comprehensive, informed, parsimonious, and consistent (Glaser, 1978; Morse, 1997). In ensuring further development of theory for this study, theoretical saturation was pursued. At the stage aimed at the development of theory, cases were no longer added to the study and iteration between theory and data has stopped, as incremental learning or improvement was minimal due to the researcher recording phenomena seen before (Glaser &

Strauss, 1967; Eisenhardt, 1989). The final product of the theory development was the formulation of the development path for the small wind sector in the country.

In ensuring the objectivity of the theoretical development throughout the research, measures were taken by the researcher to ensure that the research outcomes are the products of the ideas and experiences of the participants, and not that of the researcher’s predilections, biases, and characteristics. The researcher has maintained openness, was innovative, sensitive and intuitive, and has readily abandoned poorly supported ideas when the need arose, irrespective of the prospect and excitement initially apparent in such ideas. In achieving the objectivity of the development of the theory, the beliefs supporting the decisions taken, the methodologies adopted for this study, and the weaknesses were all acknowledged and described in the thesis.

3.5 Conclusion

This chapter provided the methodological details of this research study. The researcher justified the methodology used for the research and described in detail the conduct and processes of the research. The research design described the processes for: the data collection approaches, which involved document review and expert interviews; the policy analysis of the small wind sector; the techno-economic analysis of the systems in different locations of the country; hypothesis testing, and the proposed alternative development path. Furthermore, the data and methodology verification approaches employed for the study were presented. These approaches guide the researcher in checking data methodically, ascertaining the need for continuation, stoppage or modification of the research processes, and continual monitoring and confirmation of the analysis. The next chapter presents the data analysis and results of the evaluation of the available policies benefitting small wind energy systems in South Africa.

CHAPTER 4
POLICY EVALUATION

4.1 Introduction

Small wind energy generation is an emerging and promising electricity-generating source. In South Africa, despite the benefits and abundant wind resources, this sector has not experienced mass uptake, as the installed capacity has exhibited limited growth (Szewczuk, 2012; Milazi, 2015). The transition to small wind generation is slow in the country (Singh, 2015), and the public awareness is still unfortunately low (Hantelmann-Nawa, 2014; Mailula, 2014; Mosia, 2014). Different barriers to this transition process exist, a major one being cost effectiveness (Luthi, 2011; Shawon *et al*., 2013; Willer, 2014; Reinhard, 2015). The design and manufacturing of small wind turbines are at an early stage of technological development, thus, transition cost comes with the transmission from central to distributed generation. The cost disadvantage is further highlighted by subsidies for conventional generation and non-internalisation of external costs (EWEA, 2009a; Luthi, 2011). Other barriers include the capacity factor, wind variability, the audio-aesthetics impact, health and safety, procedural fairness, and transparency, the market power of incumbent energy firms, the valuation methods that large-scale power plants possess (Heagle *et al*., 2011; Luthi, 2011; Willer, 2014). There is a need to overcome these barriers with government legislation and incentives as a catalyst for increased market acceptance of small wind generation (US DoE, 2008; Botha, 2014). Today, countries such as the US and the UK have a remarkable growing market, credited mostly to several strong incentive programs and legislations (Heagle *et al*., 2011; Ross *et al*., 2012).

The necessary public policy is fundamental if these transition barriers have to be overcome, particularly in the delivery of effective financial incentives that will result in the development and future increase in installed capacity. Such policies should ideally include financial incentive schemes including seed and start-up funding to financially support the technology until a technology becomes matured, and it should also offer internalisation of external benefits (Sijm, 2002; Luthi, 2011). Renewable energy policies that attract little interest from the industry, risk being withdrawn, and the weakening of long-term industrial development should be avoided (Verbruggen & Lauber, 2009).

This chapter aims to evaluate existing policies for small wind generation and the necessary policy factors to be taken into consideration when formulating effective policies. To obtain these objectives, the chapter compares the available support policies benefitting small wind generation in South Africa with that of two other countries with developed markets in small wind power – the US and the UK (Whale *et al*., 2013). The two developed markets were used as benchmarks. The chapter examines two essential aspects. First, it applies a dynamic policy analysis, examining the policy development process and the growth of small wind installed capacities over time. Secondly, it applies a risk-return framework on small wind policies, thereby examining the two dimensions of investor and end-user reactions to such policies. This comparison between investor and end-user reactions tends to offer valuable insights into the legislation and incentive programs for the mass deployment of small wind energy systems. In structuring this chapter, the theoretical framework is described next, followed by the case studies for the US, the UK and South Africa. The last section makes conclusions regarding the analysed policies for the systems.

4.2 Theoretical Framework

The development of the small wind market can be illustrated in terms of the technological life cycle, which was discussed earlier in the path to technological development. The diffusion of innovation theory was used for the theoretical framework of this study, and it theoretically stimulated the role of policy-makers as key actors in the diffusion process. The diffusion of technologies tends to follow an S-shaped curve (Grubler 1997; Sanden, 2004), as indicated in Figure 4.1. According to their study, the small wind market development can be divided into three phases:

1. **Formation**: characterised by uncertainty; availability of SWT in the market; market diffusion is slow since costs are high and performance often inferior to the performance of existing technologies; the emerging technology may not fit into the technical, institutional and social environment that has evolved around the entrenched technology (Frankel 1955; Dosi 1982; Nelson & Winter 1982; Sanden, 2004).
2. **Growth**: positive feedback mechanisms or positive returns to adoption, which lead to a process of more rapid diffusion; profitability; economies of scale, both in

production and consumption; learning by doing and using that also lead to incremental product development and decreased uncertainty; and the co-evolution of a range of complementary products that decrease the cost of production (economies of scope) or increase the utility of consumption (Arthur, 1988; Sanden & Azar, 2004; Sanden, 2004; Katz & Shapiro, 1986; Wright, 1936; Hirsch, 1956; Arrow, 1962; Rosenberg, 1982; Cowan, 1991).

3. **Saturation**: grid parity is reached; well established market; further reinforcement of the position of the dominant design by moulding the surrounding technical, institutional and behavioural environment through additional lock-in mechanisms (Luthi, 2011; Sanden, 2004).

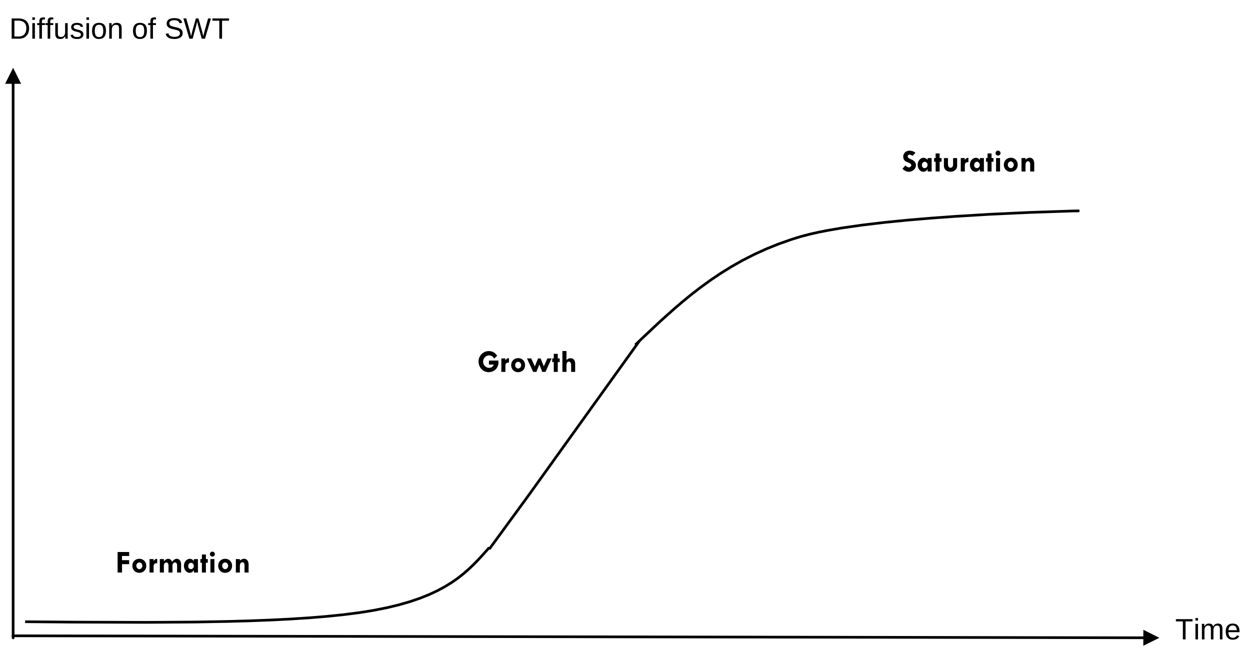

Figure 4-1: Different phases of SWT diffusion (Adapted from Sanden, 2004)

The subsequent case studies describing the development of the small wind market in the United States, United Kingdom and South Africa define this development along these diffusion phases. Both the US and the UK markets are in the growth phase (Heagle *et al*., 2011; Ross *et al*., 2012), while SA is in the formation phase. According to the definition above and the literature reviewed, none of the markets are in the saturation phase yet. As the development of the SA policy environment is relatively well documented in the literature review, a moderately condense review of this particular case study is presented here.

Several indices can be used to measure diffusion, including: installed capacity, energy generated, number of established renewable energy businesses or jobs created, measurement of performance related to goals, etc. (Gouchoe *et al*., 2002; Luthi, 2011). Each market study focused on the SWT policy, its effect on installed capacity, and the reactions and feedbacks from the turbine firms, investors, and other stakeholders to policy making. Furthermore, these market studies are structured to the different phases of the past, present and future market development with regard to the diffusion theory framework. A return-risk framework was adopted for this evaluation. The availability of data on most recent and future developments is obviously a limit to the analysis conducted in this study.

4.3 Case Study 1: Small Wind Market and Policy in the United States

4.3.1 Formation: 1970 – 2000

The energy crisis of the 1970s gave birth to the development of the modern industry of small wind turbines in the US, and the growth in the industry, driven by federal energy tax credits, state incentives, and high electricity prices, climaxed in 1983 when energy prices crashed, tax credits expired and the state incentives were jettisoned (AWEA, 2002). By 1999, electricity prices started to increase again, raising concerns about energy supply security, centralised generation, energy independence, and global warming. Several important incentive programs that mitigated the initial costs of small wind generations were enacted by state governments in the US, and all these incentive programs, resulted in increased interest in small wind energy systems (AWEA, 2002). State subsidy programs that subsidise half of the installation costs of small wind turbines are for example causing the economics of the technology to be more attractive in California, with almost 650 kW of installed small wind capacity realised in the state under the California Energy Commission’s “buy-down” rebate program since 1998 (Refocus, 2002). While this capacity is paltry, it encouraged the AWEA to launch a campaign on educating people about the benefits of small wind installations.

4.3.2 Growth: 2001 – 2012ff

The small wind energy sector in the US sold an estimated 13 400 turbines valued at about $20 million in 2001 (Bergey, 2001), owing to the impact of huge, sustained support from government support programs and policies for renewable energy. These huge support programs, which added up to $3.5 billion in 2001 (small wind turbine incentive programs inclusive), were funded through system benefit charge programs (AWEA, 2002). In the years since 2001, the country has enacted several federal, state, and utility incentive programs, in form of rebates, grants, loans, net-metering, tax credits, etc. These programs that vary regarding the funding amount, project numbers they support, and available time length benefitted small wind energy systems.

The federal incentives include grant programs such as the U.S. Treasury Renewable Energy grant (Section 1603), Federal Investment Tax Credit (ITC), Renewable Electricity Production Tax Credit (PTC); Renewable Energy Production Incentive (REPI) program; Residential Renewable Energy Tax Credit, New Market Tax Credits; Modified Accelerated Cost Recovery System (MACRS); Tribal Energy Program Grant; U.S. Department of Agriculture Rural Energy for America Program (REAP) Grants and Loans (Section 9006); and federal loan programs such as the Qualified Energy Conservation Bonds (QECBs), Clean Renewable Energy Bonds (CREBs); and the US Department of Energy Loan Guarantee Program (DSIRE, 2007; Kwartin *et al*., 2008; AWEA, 2010; Heagle *et al*., 2011; Orrell *et al*., 2013). For brevity, just a few will be highlighted.

The federal investment tax credit (ITC) for small wind energy systems is a stable and long-term policy that allows consumers to claim 30% of the total cost of the technology as a tax credit, thereby helping consumers to buy qualified technology, opening markets that were not reachable historically, and sending a positive message about the viability and promise of the industry to investors and other stakeholders (AWEA, 2010; Orrell *et al*., 2013). The credit came into existence in 2008 through the Emergency Economic Stabilisation Act of 2008 and will end in December 2016. The credit amount was strictly capped until 2009 where after the cost cap was removed by the establishment of the American Recovery and Reinvestment Act (ARRA) of 2009 (AWEA, 2010).

The Treasury RE grant (section 1603) enables commercial consumers to receive payments in the place of the ITC tax reduction for a limited time, making incentives more immediate to projects and tax payers (AWEA, 2010). The federal Production Tax Credit (PTC) enables small wind generators to claim tax credits for up to 30% of the purchase and installation cost for projects started by the end of 2013, although this grant is yet to be renewed (CSS-UM, 2014). The Renewable Energy Production

Incentive (REPI) offers incentives to new projects at public facilities that generate and distribute renewable energy, while MACRS provides an accelerated five-year depreciation of a commercial or industrial distributed wind project, thus improving its life-cycle economics (Kwartin *et al*., 2008).

The USDA REAP offers financial assistance in the form of grants (up to 25% of the project cost or a maximum of $500 000) and loans (up to 75% of the project cost or a maximum of $25 million) to agricultural farmers and ranchers and rural small businesses to procure, install, and build renewable energy systems and other energy efficiency projects (USDA, 2007; Kwartin *et al*., 2008; Orrell *et al*., 2013). The Clean Renewable Energy Bonds (CREBs), with an annual budget of $400 000 000 for all types of renewable energy projects, give interest-free and low-interest loans to qualifying public facilities and organisations without tax liability (Kwartin *et al*., 2008).

At state and local levels, several policies have also been passed to enhance the growth of small wind energy systems. These state specific programs, including net-metering, tax credits, loans, rebates, etc., continue to be fragmented and changing, but generally they are improving across regions and communities (AWEA, 2010). Net metering is offered in 43 states and the District of Columbia, enabling consumers to sell excess electricity produced to the grid (US EPA, 2013). Furthermore, Renewable Portfolio Standards (RPS) require electricity providers to generate an increasing percentage of their electricity supplies from renewable technologies, thereby ensuring that the demands for electricity to be generated from renewables are implemented in several states (Kwartin *et al*., 2008).

An excellent example of state incentive funding is found in California, as it holds the largest state market for small wind generations due to its relatively long history of generous incentives and streamlined permitting laws (AWEA, 2010). An evident incentive in the state is the Feed-in-Tariff (FIT), which enables small wind energy consumers to earn returns on their investments. The California FIT incentive program provides contracts for consumers of various utility organisations for a stated period (i.e. 10, 15, or 20 years) during which their small wind-generated electricity can be sold at a market-based time-of-use tariff (Heagle *et al*., 2011). The selling price per kWh is dependent on delivery time factors and market price referents (CPUC, 2010a). The market price referent of $0.08448/kWh was applied for contracts that commenced in

2010 for a period of 10 years, and projects must deliver less than 1.5 MW to be eligible and can be situated on either residential or commercial properties (CPUC, 2010b; Heagle *et al*., 2011). Additionally, the Emerging Renewable Program (ERP) offers qualified consumers of small wind turbines of up to 50 kW capacity a rebate for each watt installed up to a maximum of 30 kW, and the Self Generation Incentive Program (SGIP) is capped at 3 MW (Heagle *et al*., 2011; Orrell *et al*., 2013). The California net-metering program writes out more than 120 000 residential and non-residential accounts (CPCU, 2013).

Other examples of state incentive funding programs in the US include the production incentives (e.g. Washington Renewable Energy Production Incentives); production tax credits (e.g. Iowa's Renewable Energy Tax Credit); sales-tax exemptions for renewable equipment (e.g. Washington's Sales and Use Tax Exemption); and property-tax exemptions (e.g. Indiana's Renewable Energy Property Tax Exemption) (DSIRE 2007). Furthermore, development funds for clean energy are created (e.g. Minnesota's Renewable Development Fund); the establishment of state- or utility-run grant and loan programs (e.g. Massachusetts Technology Collaborative); and mandatory utility purchases of green power (e.g. Iowa's Mandatory Utility Green Power Option) (DSIRE 2007; Kwartin *et al*., 2008).

The above-mentioned policy programs have ensured the feasibility and accessibility of small wind technology and significantly increased the installed capacity in the country. Regardless of the economic recession, the small wind market in the US increased by 15% in 2009 with 20.3 MW of new capacity generated and $82.4 million in sales (nearly 10 000 units), culminating in a total installed capacity of 100 MW. This growth was credited partly, and importantly, to new and improved federal and state incentives (AWEA, 2010). The total installed capacity for the US was 170 MW in 2010 (AWEA 2011). In 2012, the market for small wind turbines increased with 18.4 MW of new capacity in sales and $101 million in investment, and a cumulative generated electricity that exceeded an estimated 216 MW (Orrell *et al*., 2013).

Excessively restrictive and onerous procedures can limit a turbine's productivity, discourage consumers and investors, and prevent the development of local industry-related businesses from communities (AWEA, 2010). For this reason, the government and other stakeholders from the small wind industry in the US have continuously collaborated to improve permitting and other administrative processes for small wind energy systems. By early 2010, nine states have passed state legislation to streamline the permitting and other administrative processes of small wind installation at state level, thereby providing these state markets with the potential for small wind generation (AWEA, 2010). Similarly, the Distributed Wind Energy Association (DWEA) published a model ordinance and guidelines in 2012 for counties, towns, municipalities, jurisdictional and neighbourhood associations, state and federal incentive agencies, wind turbine installers, property owners, advocates, etc. to significantly streamline the zoning and permitting process, thus reducing time and cost to the jurisdictional authority, and avoiding the addition of unnecessary, non-value-added cost to property owners with interest in small wind systems (DWEA, 2013; Orrell *et al*., 2013).

4.3.3 Saturation

Many industry leaders collaborated to unveil a distributed wind third-party leasing to further expand the residential market sector since 2013, and they also sought financing models with local and regional banks (similar to those for solar projects) to further achieve mass installation of small wind turbines (Orrell *et al*., 2013). For the increased installation of distributed wind projects in the agricultural and rural markets, the US Department of Agriculture's budget recommended increased levels of mandatory funding for grants and loans from the fiscal year 2014, over and above the REAP level for 2012 (USDA, 2012). The leading fifteen manufacturers of small wind turbines in the world projected an exponential sales growth of SWT in the US market that would result in a cumulative installed capacity of 1 GW by 2015 (AWEA, 2010). Furthermore, the net potential number of homes in the US utilising small wind generation by 2020 was projected at 15.1 million. The increase in investment, federal and state incentives, and several other factors will lead to the saturation of the industry in the years ahead (AWEA, 2010).

4.3.4 Case Study Conclusions

The federal, state, and utility incentives are significantly increasing the investment in and installed capacity of small wind in the US. While distributed wind application accounted for more than 68% of all wind installations, on a unit basis the off-grid small wind turbines retained the largest percentage of these distributed installations in the country between 2003 and 2012 (Orrell *et al*., 2013). In general the industry experiences sustained growth, and with the continuation of the trend in investment and policy support, it will reach saturation.

Return Factors

(a) Level of Incentive: The level of the financial support for small wind systems, in terms of the available numbers and the amount of funding, is quite high. In the formation phase, federal and state incentives were used to build interest of consumers and drive growth in the industry, but when these incentives were discarded after the crash of energy prices, the application of the technology dropped. The re-introduction and reinforcement of these financial incentives and other new ones by federal and state institutions in different forms during the growth phase significantly fuelled the surge in the small wind industry. The combination of several of these incentives like rebates, grants, tax credits, net-metering, loans and other forms of incentives from the federal and respective states, are making the economic viability of the technology more attractive, thereby inspiring individuals, small firms and farmers to invest in the US small wind market. The USDA REAP offers grants of up to 25% of the project cost or a maximum of $500 000, and loans of up to 75% of the project cost or a maximum of $25 million (Orrell *et al*., 2013). The CREBs have an annual budget of $400 000 000 and offer money interest-free to qualifying public facilities (Kwartin *et al*., 2008), while the California Energy Commission, through its Emerging Renewables Program, made available approximately $500 000 in incentives in 2012 (Kwartin *et al*., 2008).

Manufacturers attribute the growth in the small wind energy sector to the high level of support by the availability of a variety of these new and improved federal and state incentives (AWEA, 2010), although other factors were equally mentioned. The ITC passed in 2009 saw a 15 percent growth in small wind turbine sales in that same year regardless of the ongoing economic recession, and this growth was made possible primarily by the ITC according to a survey by the American Wind Energy Association of turbine manufacturers (AWEA, 2010; Querejazu, 2012). The REAP grants and loans funded about 200 small wind projects in 30 states in 2011, with a total generation of 5.8 MW (Querejazu, 2012).

(b) Duration of Incentive: The federal investment tax credit (ITC) is legislated for 8 years. The RE Production Tax Credit applies to the first 10 years of operation. The California FIT program is guaranteed for a specified period of 10, 15, or 20 years.

(c) Wind Resource: The US has an annual wind potential of 68 000 TWh, lower 48 states (U.S. DoE, 2014; CSS-UM, 2014).

Risk Factors

(a) Policy Stability: The medium to long-term security that the financial incentives from the federal institutions and states provide to investors is a major booster for the industry. These incentive programs did not experience any abrupt negative changes in the past, except during the formation phase (AWEA, 2002), and rapid and decisive actions have been taken at critical times during the policy development process to address potential problems. While policies at state and local levels are fragmented and changing, they are improving in general (AWEA, 2010). With the sustained general support for small wind generations from both the government and legislators in the country, further positive policy changes are expected to continue.

(b) Cap: There are incentives without any cap (e.g. the federal Production Tax Credit) and incentives with programmatic caps, budget caps, or capacity caps. The amount of the federal ITC was strictly capped initially until the enactment of The American Recovery and Reinvestment Act (ARRA) of 2009, which removed the cost caps (AWEA, 2010). While under the California FIT program, qualifying projects must generate less than 1.5 MW, and beneficiaries of the program cannot partake in other rate-payer incentives such as RPS programs (CPUC, 2010b; Heagle *et al*., 2011).

(c) Administrative process: There is continued improvement of the administrative process for the installation of small wind energy systems in the US. The zoning and permitting processes are being significantly streamlined, the interconnection regulations are being standardised, ordinances and guidelines are being issued, and all these are reducing cost and saving time (Orrell *et al*., 2013; DWEA, 2013). Many states are enacting legislation to streamline administrative and permitting processes at the state levels, with an estimated 25 000 different local zoning jurisdictions in the country (AWEA, 2010).

4.4 Case Study 2: Small Wind Market and Policy in the United Kingdom

4.4.1 Formation: 1980 – 2001

The restructuring and privatisation of the energy sector in the late 1970s and the 1980s were mainly responsible for the development of renewable energy for electricity generation in the United Kingdom (IRENA-GWEC, 2013). The period of the UK Conservative government of 1979 saw the privatised regional electricity firms being allowed to buy electricity from the renewable energy producers at a premium price, as that government was not favourable to providing subsidies and research grants to support renewable technologies (Elliot, 2005). This led to the establishment of the first commercial wind farm in Cornwall. Afterwards, in the early 1980s, wind energy started gaining promotion and the development of demonstration projects across the country was funded by the government to 'prove' the technology (Connor, 2003; Price, 2006).

The first concrete opportunity to deploy renewable technologies in the UK was provided by the Electricity Act of 1990, as the act contained the proposed Non-Fossil Fuel Obligation (NFFO), which sought to provide financial support for renewable and nuclear energy (IRENA-GWEC, 2013). The NFFO was in operation from 1990 to 1998. The Renewable Obligation (RO) replaced the Non-Fossil Fuel Obligation in 2002, and it is a kind of tradeable green certificate. The RO committed all licensed electricity suppliers to supply specified capacities of electricity from renewable sources, and permitted the trading of Renewable Obligation Certificates (ROCs), for the delivery renewable generation at the lowest cost (Pollitt, 2010; IRENA-GWEC, 2013).

4.4.2 Growth: 2002 – 2012ff

In the UK, the interest in small wind generation is increasing, and market development is being encouraged with a range of supportive policy programs and the reformation of some regulations to ease installations at project sites (Carbon Trust, 2008; Pollitt, 2010). The combination of these policies and regulations to develop small wind energy systems was categorised into three types by the Carbon Trust (2008), namely: fiscal (concerning the economics of installation); planning regulations and guidance; and building regulations.

The fiscal policies are programs that affect the economics of small wind installations such as the Clear Skies Scheme (CSS), Low Carbon Buildings Programme (LCBP), Renewable Obligation (RO), and Feed-in-Tariff (FIT). The Clear Skies Scheme, operated from 2002 to 2007, assigning grants valued at £10 million to renewable generation including small wind systems, with £5.5 million available for 316 community projects and £4.2 million for 6633 household projects. The scheme was replaced by the Low Carbon Buildings Program (Willcock & Appleby, 2009). The Low Carbon Buildings Programme (LCBP), introduced by the Department of Business, Enterprise and Regulatory Reform in 2006, offers budgeted grants of £30 million to householders, public sectors, and charitable organisations, to reduce the capital costs of projects (Willcock & Appleby, 2009). An additional supplementary budget of £50 million was committed to the initial amount in December 2006, and grant levels were revised in 2008 after admittance that upfront costs still remained unfavourable (Willcock & Appleby, 2009). Households can access up to £1 000 per kW of installed capacity, up to £2 500 in total or 30% of the total eligible costs (whichever is lower) per property, while the public sector and charitable organisations are entitled to up to £1 million or 50% of the installation costs (Carbon Trust, 2008).

The Renewable Obligation (RO) introduced in 2002 to stimulate utility-scale renewable projects was amended by the UK government in April 2007 to include the participation and promotion of small-scale generation, as most of these systems do not generate enough capacity per year to benefit from the Renewable Obligation Certificate (Carbon Trust, 2008; Willcock & Appleby, 2009). The amendment made for the combination of the capacities of several small wind turbines possible so as to qualify for ROCs, and it also enabled the generators to engage agents to act on their behalf. In 2012, the RO support tariffs were comprehensively reviewed, and the new tariffs were legislated in April 2013 (DECC, 2013). The RO will not allow new capacity on March 31, 2017, but the accredited capacity will be in operation for an additional 20 years (ending on March 31, 2037), where after the RO will go through transition into a certificate purchasing scheme in the final years so as to reduce volatility during this period (DECC, 2013).

The Feed-in Tariff was introduced as a financial incentive for small-scale generation in April 2010, opening generation to households, businesses, and communities with a capacity less than 5 MW (IRENA-GWEC, 2013). The incentive, created by the Energy Act of 2008, offers consumers £0.045 to £0.345 (generation tariff) per kWh of wind generated electricity, and an extra tariff of £0.03 (export tariff) per kWh of energy exported to the grid (OfGEM, 2010; Heagle *et al*., 2011). Depending on the installation date, these tariffs are valid for the approved lifetime of the installation. However, the FIT Comprehensive Review completed in December 2012, recommended the improvement of value for money and the reduction of support tariffs due to falling costs (DECC, 2013). The UK FIT has been adjudged as successful since its inception, boasting with more than 400 000 RE installations on the Central Feed-in Tariff Register at the end of June 2013 (DECC, 2013).

While small wind turbine sales have been lower in the UK than in a country like the US, historically, the British Wind Energy Association indicated that the UK market is growing (Carbon Trust, 2008). There were approximately 14 000 small wind installations (100 kW maximum) in the UK in 2008, with an installed capacity of about 26 MW (Willcock & Appleby, 2009). By 2010, there were over 16 000 installations, generating over 40 MW (Renewable UK, 2011; Minderman *et al*., 2012). Furthermore, about 19 854 small wind turbines were installed by the end of 2011, leading to an installed capacity of about 65 MW (WWEA, 2013).

Other important considerations when installing small wind technology are land-use planning, permitting and other administrative processes. In 2008 different restrictions applied and all installations needed planning permission (Carbon Trust, 2008). However, the new Permitted Development Rights (PDRs), which reduce the need for site-specific planning processes, is expected to be beneficial to domestic installations (Carbon Trust, 2008). Similarly, the Renewables Obligation Order (ROO) amends the RO for small-scale electricity generation, thereby simplifying the administrative process to be similar to the simple process enjoyed by large scale generation (Willcock and Appleby, 2009).

4.4.3 Saturation

The UK government proposed to terminate the Renewable Obligation program from 2017 and institute an expanded Feed-in Tariff for renewable technologies (IRENA-GWEC, 2013). In June 2013, the Department of Energy and Climate Change (DECC) and Defra launched a joint £15 million Rural Community Energy Fund (RCEF) to provide grants and loans for qualifying rural communities in England to finance the costs associated with feasibility studies and planning permission applications for local renewable energy projects (DECC, 2013). Similarly in 2012, the DECC issued the Levy Control Framework (LCF) and Spending Review (presented in Table 4.1) for every low carbon electricity support policy, which include the Renewables Obligation, Feed-in Tariff, and Contracts for Difference under the Electricity Market Reform (EMR) proposals (DECC, 2013).

Table 4-1: Low carbon electricity (including renewables) policy levies (upper limits)

Year	2015/16	2016/17	2017/18	2018/19	2019/20	2020/21
Price	£4.30bn	£4.90bn	£5.60bn	£6.45bn	£7.00bn	£7.60bn

Source: DECC, 2013

4.4.4 Case Study Conclusions

The small wind market in the United Kingdom has experienced significant growth in recent years and is still growing, although a lot still needs to be done to get the industry to saturation phase. There are indications of further industry growth with Scottish and Southern Energy's purchase of 2 000 Swift turbines for domestic installation, the partnership of British Gas and WindSave for a similar project, and the initiative to integrate micro-generations into newly built generation plants by local authorities (Willcock & Appleby, 2009).

Return Factors

(a) Level of Incentive: The level and value of incentive schemes introduced to expand the small wind market is high. The LCBP, for example, offers budgeted grants of £80 million, and later in 2008 revised it upward (Carbon Trust, 2008). The Feed-in Tariff program had more than 400 000 installed units to its credit by June 2013 (DECC, 2013). In a bid to reduce carbon emissions from the built environment in the UK, the development of a number of incentive schemes for market growth had increased the interest and number of small wind installations (Bergman & Jardine, 2009; Willcock & Appleby, 2009; Renewable UK, 2010).

(b) Duration of Incentive: The RO for existing installations after March 2017 will be valid for an additional 20 years (DECC, 2013). The Feed-in Tariff is guaranteed for the approved lifetime of the installation (Heagle *et al*., 2011).

(c) Wind Resource: The UK has an estimated wind resource of over 50 TWh per year. The wind is usually strongest in winter and weakest in summer, stronger during the day and weaker at night (DTI UK, 2001).

Risk Factors

(a) Policy Stability: The incentive programs are long-term and abrupt changes to policies had not occured to cause uncertainty. There were changes made to policies in April 2010, which included the extension of the Renewable Obligation program for new installations from 2027 to 2017, providing more long-term certainty to investors (IRENA-GWEC, 2013). According to the DECC (2013), the RO and FIT program will continue to accelerate the deployment of small wind generation in the foreseeable future.

(b) Cap: Incentive schemes are capped in terms of capacity and budget. The Feed-in Tariff is guaranteed for a project generating not more than 5 MW (IRENA-GWEC, 2013). Furthermore, both the FIT and RO have annual budgetary caps, although the caps are high (DECC, 2013).

(c) Administrative Process: Planning permission was required and numerous restrictions exist, causing delays. However, there is a continued effort to make the administrative process less bureaucratic. The new Permitted Development Rights are expected to alleviate the necessity for site-specific planning processes (Carbon Trust, 2008), and the Renewables Obligation Order is streamlining the administrative process for small-scale installations (Willcock & Appleby, 2009). Documents on planning guidance and administration for small wind generation are available and include the Planning Policy Statement (PPS) 22, Delivering Sustainable Development, etc.

4.5 Case Study 3: Small Wind Market and Policy in the South Africa

4.5.1 Formation: 2002 – 2014ff

The renewable energy target of 10 000 GWh by 2013 initiated by the Department of Energy in 2002, and the renewable energy project subsidies provided through the Renewable Energy Fund Subsidy Office (REFSO) have mainly influenced the country's renewable energy policy (Edkins *et al*., 2010), before the IRP document was introduced. South Africa has a meagre, total installed small wind capacity of 0.56 MW (Szewczuk, 2012). To motivate potential investors, enable rapid growth of the renewable energy market, and (seemingly) initiate growth in small-scale generation like small wind energy systems, the Renewable Energy Feed-in Tariff (REFIT), Renewable Energy Independent Power Purchase Procurement Programme (REIPPPP), Standard of Offer, Net Metering, Electricity Generation Tax, Green Fund, and Green Efficiency Program were established.

The Renewable Energy Feed-in Tariff (REFIT) was initially proposed in 2003, but failed as a result of bureaucracy and the red tape involved in licensing, and rumours of the REFITs being slashed with time (Fritz, 2013). The REFIT was established in March 2009 by the National Energy Regulator of South Africa (NERSA) as a financial incentive, and it aroused an increased interest to develop renewable energy projects by IPPs (Edkins *et al*., 2010). During the first phase of the revised REFIT the tariff for wind energy was R1.25/kWh and was to be reviewed annually for the first five years thereafter and every three years afterwards so as to prevent a lock-in of inadequate tariffs (NERSA, 2011). However, the next review of the inflation-indexed REFIT tariffs that was expected to be released in 2011 was jettisoned and substituted with the REIPPPP (Fritz, 2013). The key principles that strengthened the REFIT program included: guaranteed access to the national grid; a guaranteed purchase price for a fixed duration; an obligation to purchase and to discharge the power generated; the potential to set a cap on the maximum available subsidy per year, etc. (Edkins *et al*., 2010). However, dedicated small projects allocated to the REFIT program only covers 1 MW – 5 MW (NERSA 2011; Fritz, 2013). Furthermore, Whelan and Muchapondwa (2009) argued that, since the tariff is only paid when wind-generated electricity is supplied to the grid, the REFIT will not benefit small wind turbine consumers as their turbines will mostly generate electricity for personal consumption rather than supplying it back to the grid. These authors expressed that, if the objective is to grow the share of renewable energy in the country's energy mix, the REFIT should be modified to include consumers that generate for self-consumption and those that export back to the grid.

Similarly, the Renewable Energy Independent Power Purchase Procurement Programme (REI4P) was introduced in 2011 as an incentive program to support the growth of renewable energy, although it has concentrated predominantly on utility-scale generations (Frost & Sullivan *et al.*, 2013; Singh, 2015). Delays characterised the bidding and implementation processes, as most parties are inexperienced in handling the complex contracts dealing with projects of such magnitude, and this caused uncertainty in the market (Frost & Sullivan *et al*., 2013). Although the program is a success (WWF-SA, 2014), and the final Request for Proposal (RFP) released on August 21, 2013 signified the intention of the DoE to initially procure 100 MW of "small capacity" projects generating between 1 – 5 MW in a separate stream, and probably 200 MW subsequently (DoE IPP, 2012; Milazi, 2015), much more is required to specifically support the sub-1 MW renewable sector (Frost & Sullivan et al, 2013; Kruyswijk, 2014).

The Standard Offer Program (SOP) was a rebate incentive program introduced by ESKOM for a trial period in June 2012 (through its Integrated Demand Management) to increase energy efficiency through small wind generations and other small-scale renewable technologies (ESKOM-IDM, s.a.; Frost *et al*., 2013**).** The incentive program covers the installation of turbines generating capacities from a minimum of 10 kW to a maximum of 1 MW installed peak capacity, and the stakeholders of approved installations are paid a rate of R1.20 per kWh under the Standard Offer over a Standard Offer contract period of 3 years (ESKOM-IDM, s.a.; Reinecke *et al*., 2013). The first cap offer of 10 MW was accepted well and was therefore increased to 20 MW (Reinecke *et al*., 2013).

Net metering, an incentive which enables the owners of small-scale generators to pay for the difference in electricity between their total exports to the municipal grid and total import from the grid, is yet to have its regulations drafted in South Africa. This fact is discouraging residential and commercial end-users from investing in small-scale renewable energy generations (Frost *et al*., 2013). Furthermore, municipal governments limit economics through the failure to allow net metering (Lyons, 2014). However, NERSA has standard conditions to guide municipalities on net metering, and some municipalities are already exploiting net metering to promote small-scale generation in their domain. The Nelson Mandela Bay Municipality started its Small Scale Embedded Generation program in 2012, with NERSA allowing systems with a capacity of below 100 kW to generate without licenses. Furthermore, a formal application process was initiated by the eThekwini Municipality in 2012, establishing a Purchase Power Agreement (PPA) with the owners of generators to export surplus electricity to the grid (Frost & Sullivan *et al*., 2013). The City of Cape Town has equally implemented a program for its small-scale embedded generation, with a lower tariff as “refund” for excess energy generation and a higher energy consumption tariff, and a daily service charge (Jones, 2014). The net metering tariff is difficult to implement, and the application process is too costly and burdensome for residential consumers (Jones, 2014). Likewise, the Electricity Generation Tax introduced in 2009, with the long-term objective of achieving climate change and providing incentives for the deployment of renewable technologies, imposed a tax of R0.035/kWh on electricity generated from non-renewable sources, and it is collected at the source by the electricity generators (Seymore *et al*., 2009; Frost & Sullivan*et al*., 2013). Therefore, a small-scale electricity generator has the opportunity to avoid being levied with this tax.

The Green Fund is a national financial instrument administered by the Development Bank of Southern Africa (DBSA) under the auspices of the Department of Environmental Affairs (DEA) and the National Treasury, and it is aimed at providing catalytic finances to facilitate investment in green initiatives and support South Africa’s transition towards a green economy (DEA, s.a.; Frost & Sullivan *et al.*, 2013). The financial support is provided as either grants (recoverable and non-recoverable); loans (concessional rates and terms); or equity, and the potential applicants and investees include the private and public sectors (DEA, s.a.). A total of R1.1 billion (R300 million for 2012/13; R500 million for 2013/14; and R300 million for 2015/16) was allocated for the fund (Frost & Sullivan *et al*., 2013). Similarly, the Green Energy Efficiency Fund (GEEF) program, managed by the Industrial Development Corporation (IDC), and supported by the German Development Bank, is a loan that is offered to people generating renewable energy at an interest rate of 2%. The loan amount ranges between 1 and 5 million for a period of 15 years (IDC, 2012; Reinecke *et al*., 2013).

4.5.2 Case Study Conclusions

The small wind industry in the SA is clearly at the formation phase. While there is potential for growth in this sector, this will be highly dependent on the development of more country-specific regulatory frameworks targeted specifically at small-scale renewable generations and streamlined administrative processes.

Return Factors

(a) Level of Incentive: The level of support that covers SWT is almost non-existent. According to Milazi (2015), there is practically no incentivized tariff for small-scale wind projects. Almost all the incentive programs for renewable energy in SA are aimed at large-scale generations. Special incentives that incite growth in the markets in developed countries such as feed-in tariffs are not available for small wind generations. Most of the available incentives allocated to small renewable projects, only cover generated capacities ranging between 1 MW and 5 MW, which small wind generators cannot realise. The procurement of wind energy projects in the REI4P is based on price (kWh tariff) competitiveness, and small turbines cannot compete on this basis (Kruyswijk, 2014). Low tariffs have the tendency to increase demand, because a typical consumer will offset his/her aim at saving as much as possible (Botha, 2014).

(b) Duration of Incentive: Apart from the REFIT and REI4P that are primarily aimed at utility-scale generation, the Standard Offer Program has a contract period of 3 years (Reinecke *et al*., 2013). The net metering program for small-scale embedded generation, the Electricity Generation Tax, and the Green Energy Efficiency Fund do not have duration limits, while the Green Fund has financial commitments up to 2015/16.

(c) Wind Resource: The country has a wind power generation potential estimated at 80.54 TWh, that can be realised with an installed capacity of about 30.6 GW (Edkins *et al*., 2010). The Western Cape and parts of the Eastern and Northern Cape harbour the best of the wind resources (Hagemann, 2008). Average wind speeds are in excess of 5 m/s or 6 m/s in several areas along the coast and stretches of the Dranskenberg escarpment in the Eastern Cape and Kwazulu-Natal (DME, 2006; Whelan & Muchapondwa, 2009).

Risk Factors

(a) Policy Stability: Most of the incentives lack clarity, frequently changed, and experienced delayed financial commitment, causing considerable uncertainty. The feedback from participants shows a lack of clarity on net metering regulations, which is discouraging investment for potential residential and commercial consumers (Frost & Sullivan *et al*., 2013). Pegels (2010) queried that the monopolistic market situation where only ESKOM procure the renewable energy-generated electricity in the REFIT program, causing uncertainty and inhibiting investment. Furthermore, the short-term duration of the REFIT tariffs and the continual subjection to review and reauthorization by the government deter investments (Frost & Sullivan *et al*., 2013). Concerns were equally raised for the success of the REI4P with regard to the usual limited long-term financial commitment and support from the government, often resulting in the limited execution of projects and uncoordinated methodology. (Frost & Sullivan et al, 2013).

(b) Cap: Both the REFIT and REI4P incentives allocated to small-scale renewable projects were capped at generated capacities of 5 MW, even though a minimum capacity of 1 MW can benefit from the programs. The capacity cap for the SOP was increased from 10 MW to 20 MW following positive responses from applicants (Reinecke *et al*., 2013), while the Green Fund has a budget cap of R1.1 billion up to 2015/16 (Frost & Sullivan et al, 2013).

(c) *Administrative Process*: Permitting, approval, bidding and other administrative processes were hampered by delays, bureaucracy, etc., due to inexperience, the lack of technical capability, and other related skills. At the moment, there is no nationwide regulatory framework for connecting small-scale wind projects to distribution networks (Milazi, 2015). The approvals for small-scale embedded generations in municipal departments are challenging as most of them do not possess the neccessary technical capacity and skills (Frost & Sullivan *et al*., 2013). The first REFIT program proposed in 2003 failed due partly to bureaucracy (Fritz, 2013). The net metering tariff is difficult to implement due to challenges of cross tariff-year arbitrage, tax implications, etc., and the application process for residential consumers is arduous (Jones, 2014). The bidding and execution processes of the REI4P projects experienced delays as a result of the inexperience in the administration of such complex contracts, leading to unplanned extended costs and market uncertainty (Frost & Sullivan et al, 2013).

4.6 Conclusions and Discussion

This chapter tested the policy sub-hypothesis for this research study by analysing and establishing the effects of the available policies benefitting small wind energy systems on the viability and future growth of the sector in South Africa. The policy sub-hypotheses tested are:

Sub-Hypothesis H_1: The viability and future growth of the small wind sector in South Africa is limited by the presently available policies benefitting the systems.

Sub-Hypothesis H_0: The viability and future growth of the small wind sector in South Africa is not limited by the presently available policies benefitting the systems.

The results from the policy evaluation of the small wind sectors in the three different countries demonstrated that the different levels of deployment are largely influenced by the return-risk measures, as outlined in Table 4.2 below. While both the US and the UK markets are considered to be developed and SA in infancy, the deployment level can be categorised as high in the US, medium in the UK, and low in SA.

Table 4-2: The impact of return-risk factors on the level of deployment

	U.S.	**UK**	**SA**
Deployment level	High	Medium	Low
Level of incentive	++	+	–
Duration of incentive	+	++	–
Wind resource	++	+	+
Return	**++**	**+**	**–**
Policy stability	++	++	–
Cap	++	++	++
Administrative Process	++	0	–
Risk	**++**	**++**	**–**

(++ = very favourable; + = favourable; 0 = medium; – = unfavourable)

The return factors analysed for the markets indicated very favourable conditions (++) in the US, favourable conditions (+) in the UK, and unfavourable conditions (–) in SA. Furthermore, the analysis of the return related factors showed that financial incentive support is very favourable in the US (++), as there are numerous federal, state, and local financial supports in form of rebates, grants, tax credits, net-metering, loans and the funding amounts are very high; favourable in the UK (+), with relatively fewer incentive programs compared to US and reductions have even been recommend in FIT tariffs; and unfavourable in SA (–), as financial support is almost non-existent for small wind generation and almost all available incentive programs are aimed at large-scale utility generations. While the duration of incentives are 8 years (ITC), 10 (PTC), and 10, 15, 20 years (California FIT) in the US (+); the RO is valid for 20 years and the FIT is guaranteed for the approved lifetime of the installation in the UK (++); and the SOP Program has a contract period of 3 years and duration of other programs benefitting SWT are not specified and sometimes stopped abruptly in SA (–). The wind potential is in the US is 68 000 TWh U.S. (++), 50 TWh on land per year in the UK (+), and 80.54 TWh in SA (+).

The risk factors indicated very favourable conditions in the US (++), very favourable conditions (++) in the UK, and unfavourable conditions (–) in SA. Further analysis under risk factors showed that policy stability are very favourable (++) in the US and UK, as financial incentives have long-term security and there has not been any abrupt negative changes to these incentives in the past, except during the formation phase in the US; and unfavourable (–) in SA due to inexperience, lack of clarity and frequent changes of some of these incentive programs. The incentive caps are very favourable (++) in the three countries analysed, as most of the capacity caps are high and in some cases uncapped, and likewise, the budgetary caps are high. The administrative processes are very favourable (++) in the US, as zoning and permitting processes are being significantly streamlined, interconnection regulations standardised, ordinances are being issued, and several states enacted legislations streamlining administrative and permitting processes; medium (0) in the UK, as planning permission is required and numerous restrictions exist causing delays, although the new Permitted Development Rights and the Renewables Obligation Order are helping to streamline the administrative process for small-scale installations; and unfavourable (–) in SA due to bureaucracy, lack of standard guidelines, lack of clarity, lack of technical capability, and other related skills.

The case study of the US and the UK illustrated the synergy between the return and risk factors in producing the best results. Both the return and risk sides of the equation are very favourable (++) in the US, thus leading to a high level of deployment. The situation in the UK indicated that, the implementation of numerous incentive programs will possibly increase the level of deployment, although this is sensitive to risk barriers such as policy instability and less-coordinated administrative processes. Therefore, it can be deduced that, the availability of several incentives is an important condition for the increase in installed small wind capacity, however, effective deployment will only occur if policy risks are properly handled.

The South African small wind market demonstrated no favourable return and risk factors. The low level of deployment in South Africa described what the expectations should be in a market where there is an absence of favourable return and risk factors, even though there is a favourable wind resource. Therefore, this study has shown that, return-risk factors in policy formulation play an important role in determining the level of small wind market deployment and development.

In conclusion, the results established that the small wind sector in the country is not being supported by favourable policies. All the success criteria for the policy sub-hypothesis of this study have been met and supported by the research findings. Thus, the requirements of *Sub-Hypothesis* H_1, that the viability and future growth of the small wind sector in South Africa is limited by the presently available policies benefitting the systems, have been fulfilled.

Accordingly, the limitations relating to the available policies benefitting the small wind sector in South Africa, as identified and established by this study, include:

- Insufficient financial incentives
- Policy uncertainty
- Poor administrative processes
- Absence of a long-term policy plan/path for a free sustainable market development

While the introduction of more financial support programs is required for the development of the small wind sector in the country, a continued and sustained growth for the market is more desirable, and these demands for an alternative development path can ensure that the market becomes self-sustainable.

Like any research, this analysis is subject to some limitations. The difference in timing (year) of the introduction of the financial incentives in the different countries may influence the variation of the market deployment. Furthermore, complete and up-to-date data on small wind generation in South Africa are not readily accessible, and the relative lack of research literature on the small wind sector is apparent.

The next chapter evaluates the technology performances of small wind energy systems in South Africa and assesses the technological development potentials.

CHAPTER 5
TECHNOLOGY PERFORMANCE EVALUATION

5.1 Introduction

Public support policy programs are required to promote the growth of renewable energy and influence the behaviour of developers and consumers, as analysed in the last chapter for small wind energy systems. However, for the successful application of such programs, it is essential to evaluate and provide information on the energy productivity of installations, the economics involved in all phases of the project, and environmental benefits for informed policy development and implementation (Luthi, 2011).

This chapter evaluates and establishes the technology performance of small wind energy systems in South Africa and the impact on the viability and future growth of the sector. The objective here is to examine the techno-economic performance of small wind energy systems in different locations of South Africa, and these include analysing and determining the energy productivity and economic viability. Technology and performance standards may prove invaluable in advancing efficient end-use technologies at the end-user level (OECD & IEA, 2003), as inefficiency, mechanical faults, and the low energy yield of turbines are one of the main reasons identified for the low growth of the technology (Ani *et al*., 2013; Reinhard, 2015).

Small wind generation in South Africa is location dependent (Wright, 2014). Considering the variation in wind resources in the country and the large expanse of the geographic area, this study categorised the country into four different regions. Three locations were selected per region, and these regions were termed Cape Peninsula, South-Eastern region, Central region, and Northern region (Kruger *et al*., 2010). The Cape Peninsula region comprised of three selected sites for evaluation namely, Cape Town, Oudtshoorn, and Worcester. Cape Town is situated in the northern region of Cape Peninsula in the Western Cape, Oudtshoorn and Worcester are also cities located in the Western Cape. The South Eastern region comprised of Port Elizabeth, Grahamstown, and Richards Bay. Port Elizabeth, nicknamed "the windy city", and Grahamstown are situated in the Eastern Cape Province, while Richards Bay is located on a coastal plain in the KwaZulu-Natal province. The South African map showing the different regions and sites considered for analysis is presented in Figure 5.1.

Figure 5-1: Map of SA showing the different regions and site locations under consideration (http://www.nationsonline.org/oneworld/map/za_provinces_map2.htm)

De Aar, Bethlehem, and Potchefstroom were selected for the Central region in this study. De Aar is a town centrally located in the Northern Cape province, Bethlehem is situated on the Liebenbergs river in the eastern Free State province, while Potchefstroom is in the North West Province, and located on the Mooi river banks, west-southwest of Johannesburg. The Northern region is made up of Johannesburg, Nelspruit, and Polokwane. Johannesburg is situated on the high-veld plateau in the Gauteng province, and has a subtropical highland climate. Nelspruit, the capital of the Mpumalanga province, is located in the north-eastern part of the country, while Polokwane is the capital of the Limpopo province.

Purpose sampling was used for the selection of the locations for this research. The selection of the twelve specific locations was based on sites with the most complete and available wind data in the different regions considered during the period under study.

5.2 Energy Performance

The energy generated by a wind energy system at a given site during a related period of time is subjective to the power response of the system to different wind velocities, wind regimes and wind speed distribution (Gokcek & Genc, 2009). The energy performance of a small wind energy system is affected mainly by the on-site wind resource and the accuracy of the turbine rating (Willcock & Appleby, 2009), and studies have shown that many small wind turbines are unable to deliver the rated power quoted by manufacturers (Gipe, 2011; Ani *et al*., 2013). This research study analysed the energy performance of selected small wind turbines located under different weather conditions. Important parameters such as the wind speed distribution of all the sites under study and the annual energy output of the selected small wind turbines in all these considered sites were determined.

5.2.1 Wind Distribution

A potential site's wind characteristics are quite influential to determine the amount of energy produced by a turbine (Gokcek & Genc, 2009). This section analysed the wind speed characteristics and probability distribution of some selected sites in South Africa for small wind generation using the Weibull distribution function. Wind speed varies across any country as it depends on the geographical characteristics of the different locations (Shawon *et al*., 2013; Wright, 2014). This wind speed variability can be defined by the Weibull distribution function, a standard mathematical model for analysing local wind load probabilities due to the appropriateness for the extensive collection of wind data (Lun & Lam, 2000; Seguro & Lambert, 2000; Ulgen & Hepbasli, 2002; Weisser, 2003; Gupta & Biswas, 2010; Ayodele *et al*., 2012b).

The study made use of average wind speed data measured at an hourly interval over a period of 5 years (2010 — 2014), and at a height of 10m above ground level (AGL) in all the considered sites of the different regions. These data, presented in Table 5.1, were obtained from the South Africa Weather Service (SAWS). These average annual wind speeds (AAWS) of the considered regions and their respective site locations for the period 2010 – 2014 are graphically illustrated in Figures 5.2 to 5.5.

Table 5-1: Annual Average Wind Speed (m/s) of selected sites at 10m AGL (2010 — 2014)

Region	Site Location	Lat.	Long.	HASL (m)	2010	2011	2012	2013	2014
Cape Peninsula	Cape Town	33.9630	18.6020	42	5.2	5.2	5.2	5.3	5.0
	Oudtshoorn	33.6000	22.1870	328	2.3	2.2	2.2	2.4	2.4
	Worcester	33.6630	19.4180	204	4.5	4.2	4.5	4.6	4.3
South Eastern	Port-Elizabeth	33.9860	25.6160	60	5.6	5.5	5.3	5.4	5.4
	Grahamstown	33.2900	26.5020	642	4.2	4.3	4.5	4.6	4.5
	Richards Bay	28.7370	32.0930	36	3.8	3.6	3.8	4.0	4.0
Central	De Aar	30.6650	23.9920	1286	4.6	4.4	4.6	4.8	4.7
	Bethlehem	28.2490	28.3340	1689	3.1	3.4	3.3	3.0	2.9
	Potchefstroom	26.7350	27.0750	1351	2.7	2.1	2.3	2.3	2.2
Northern	Johannesburg	26.1430	28.2340	1695	4.1	4.1	4.2	4.3	4.2
	Nelspruit	25.5030	30.9110	883	3.0	1.9	2.1	2.0	2.2
	Polokwane	23.8570	29.4510	1226	2.7	2.7	3.0	3.0	2.9

From the long-term wind data determined at 10 m AGL for the Cape Peninsula, Cape Town is the windiest among the three site locations considered in the region, with the highest AAWS of 5.3 m/s observed in 2013, while Oudtshoorn recorded the least with an AAWS of 2.2 m/s in 2011 and 2012. The South Eastern region has the site locations with the highest average annual wind speed in all the different regions, having an AAWS of 5.6 m/s throughout the measured period of 2010 – 2014. The highest AAWS in the region was recorded in 2011 in Port Elizabeth, while the least AAWS (3.6 m/s) occurred in 2011 in Richards Bay. For the Central region, De Aar is the windiest location. The highest AAWS (4.8 m/s) was recorded in De Aar in 2013, while Potchefstroom has the least AAWS (2.1 m/s) in that region in 2011. In the Northern region over the considered years, the AAWS ranges from 1.9 m/s to 4.3 m/s. Johannesburg recorded the highest AAWS in 2013, while the least wind was recorded in 2011. Finally, it is clear that both the Cape Peninsula and South Eastern region experienced better wind resources for the years under consideration when compared to the Central and Northern regions.

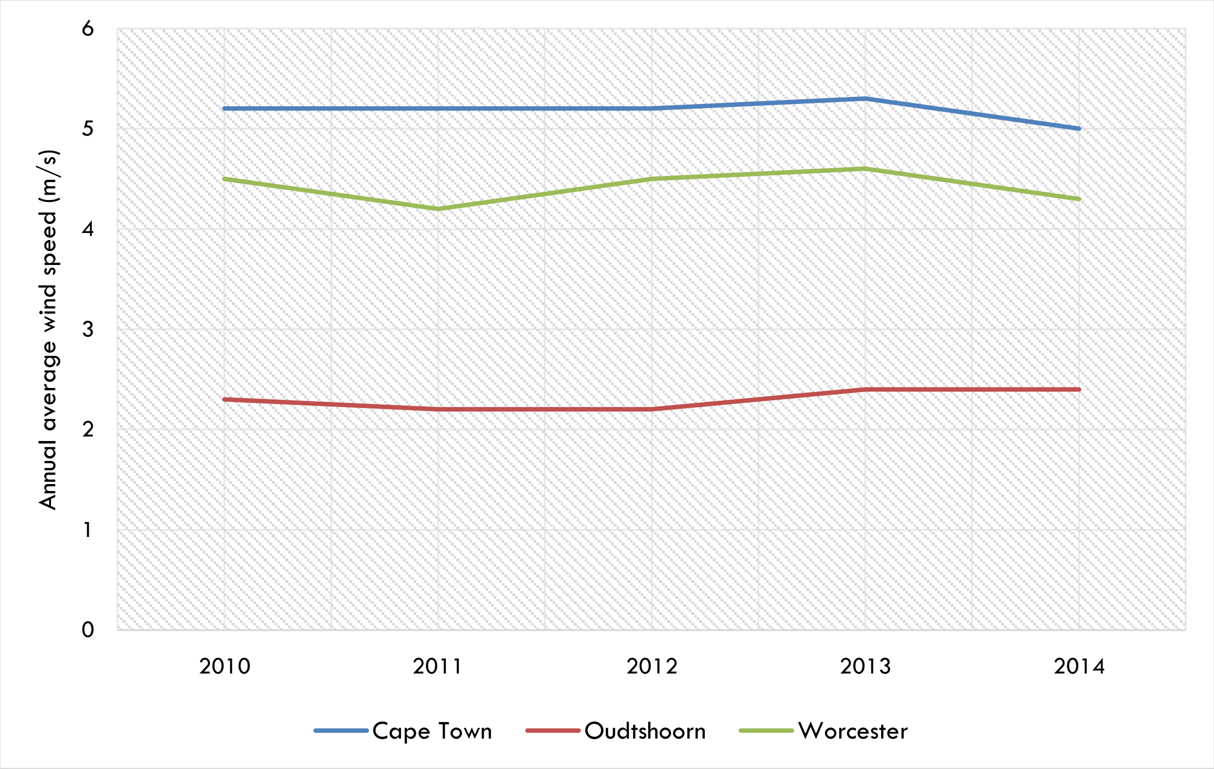

Figure 5-2: AAWS of Cape Peninsula region from 2010 — 2014 at 10m AGL

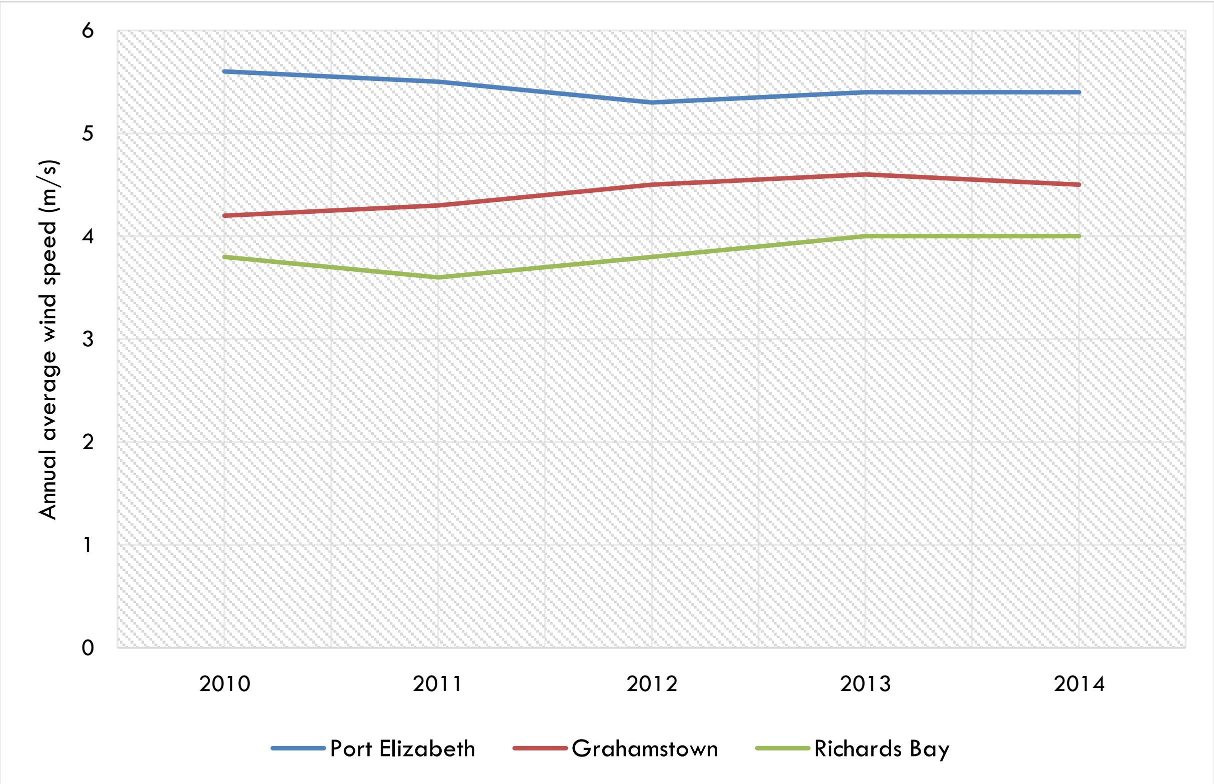

Figure 5-3: AAWS of South Eastern region from 2010 — 2014 at 10m AGL

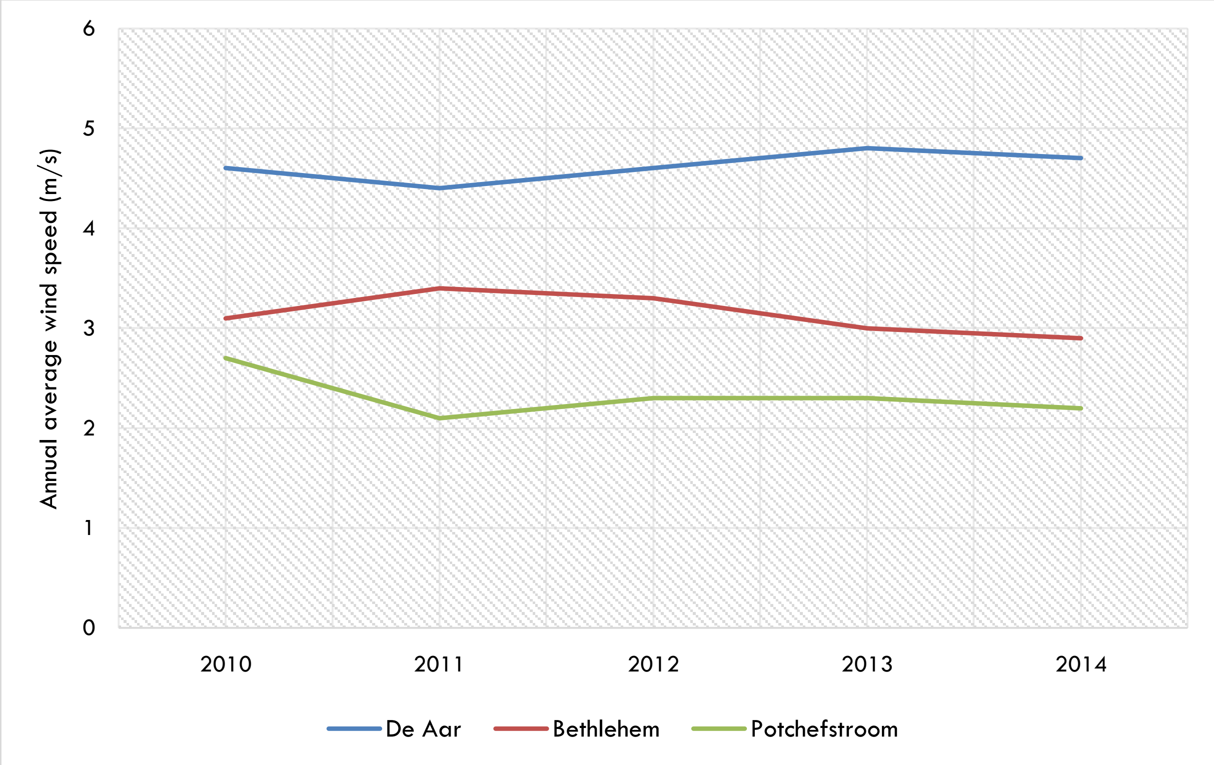

Figure 5-4: AAWS of Central region from 2010 — 2014 at 10m AGL

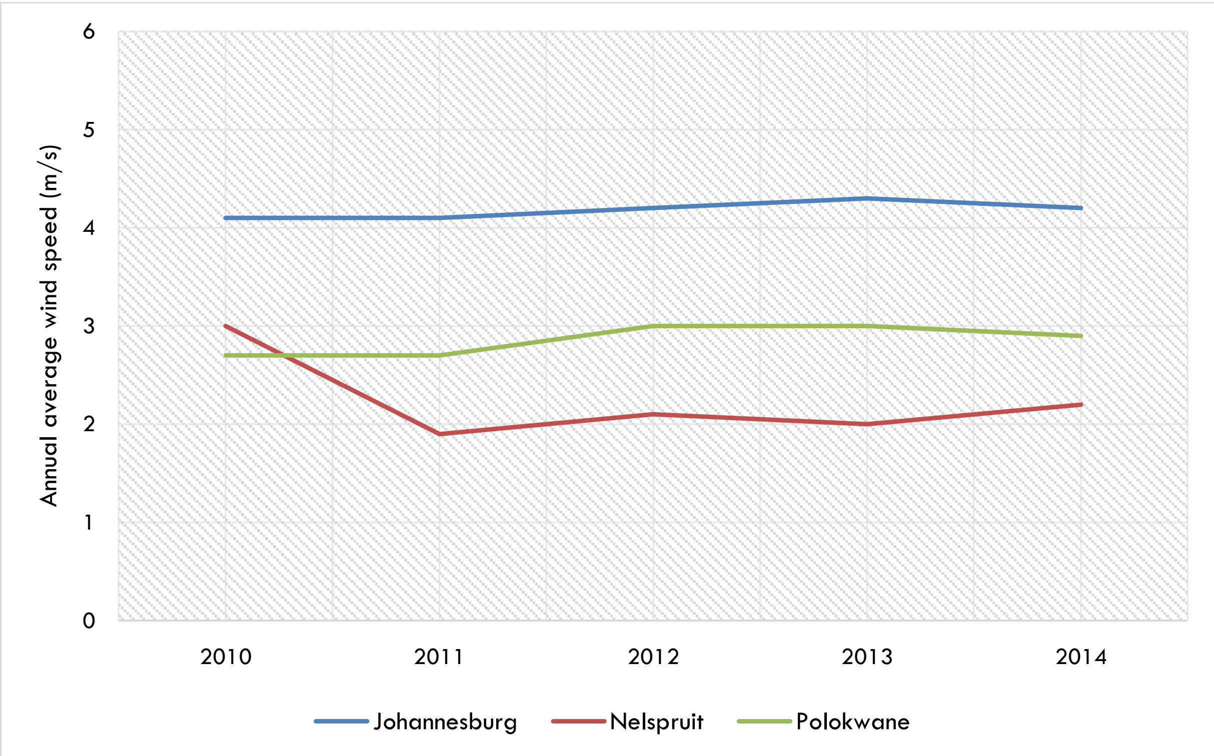

Figure 5-5: AAWS of Northern region from 2010 — 2014 at 10m AGL

The wind variation for a normal site is generally described by the Weibull distribution, and it indicates the percentage of time a certain wind speed occurs in a given site (Manwell *et al*., 2002; Gagliano *et al*., 2012; Ani *et al*., 2013). The Weibull distribution is expressed by the equation:

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} e^{-(v/c)^k} \quad (1)$$

Where $f(v)$ means the probability of wind speed (Weibull) distribution, v is the wind speed, k is the Weibull distribution shape factor, and c is the distribution scale factor.

The two factors, k (dimensionless) and c (m/s) are computed from the long-term wind data for a selected site, and they control the profile of the Weibull distribution curve (Gagliano, 2013). The Weibull shape parameter k denotes the peak level of a potential site is, while the scale parameter c indicates the intensity of the wind available on the site (Bhattacharya & Bhattacharjee, 2010; Oyedepo *et al*., 2012; Ayodele *et al*., 2012b; Gagliano, 2013). These Weibull parameters can be determined through different methods in order to fit the Weibull distribution to the measured data at a given location (Chang, 2011; Costa Rocha *et al*., 2012; Gagliano, 2013).

Based on the suitability of the Weibull distribution for all the considered site locations in this study, the relationship between the shape factor k, scale factor c, and the average wind speed v_m is expressed by the following equations (Justus *et al*., 1977; Shata, 2010; Ayodele *et al*., 2012b; Gagliano, 2013; Mostafaeipour, 2013):

$$k = 0.83\, {v_m}^{0.5} \quad (2)$$

$$c = \frac{v_m}{\Gamma(1+{}^{1}/_{k})} \quad (3)$$

These two Weibull parameters can be calculated when the average wind speed v_m and the gamma function Γ are known. Table 5.2 presents the Weibull shape and scale parameters for all the sites under consideration. The computations for these parameters were based on the mathematical models above and the data from the SAWS. The probability distributions describing the variations in wind speed for the considered sites for the years 2010 - 2014 are shown in Figures 5.6 to 5.9.

Table 5-2: Wind speed characteristics for the different sites at 10m AGL

Region	Site Location	AAWS Whole Year (2010-2014)	k	c (m/s)
Cape Peninsula	Cape Town	5.2	1.89	5.86
	Oudtshoorn	2.3	1.25	2.47
	Worcester	4.4	1.74	4.94
South Eastern	Port-Elizabeth	5.4	1.92	6.09
	Grahamstown	4.4	1.74	4.94
	Richards Bay	3.8	1.61	4.24
Central	De Aar	4.6	1.78	5.17
	Bethlehem	3.1	1.46	3.42
	Potchefstroom	2.3	1.25	2.47
Northern	Johannesburg	4.2	1.70	4.71
	Nelspruit	2.3	1.25	2.47
	Polokwane	2.8	1.38	3.07

At 10 m above ground level, the shape and scale parameters range from 1.25 and 2.47 in Oudtshoorn, Potchefstroom, and Nelspruit to 1.92 and 6.09 in Port Elizabeth. Therefore, it can be derived that Port Elizabeth is the windiest site (highest scale factor), while Oudtshoorn, Potchefstroom, and Nelspruit are the least windy sites, as the scale and shape parameters respectively signify the wind intensity and the peak level of a potential site is (Ayodele *et al*., 2012b; Gagliano *et al*., 2013). The probability of observing higher wind speeds in the Cape Peninsula is the greatest in Cape Town, and the greatest in Port Elizabeth in South Eastern region. For the Central region, De Aar has a higher probability of recording high wind speeds than the other two sites in that region, while Johannesburg has the highest wind probability in the Northern region. This study confirmed that the Cape Peninsula and the South Eastern regions have higher probabilities of recording high wind speeds in South Africa when compared to the other regions considered.

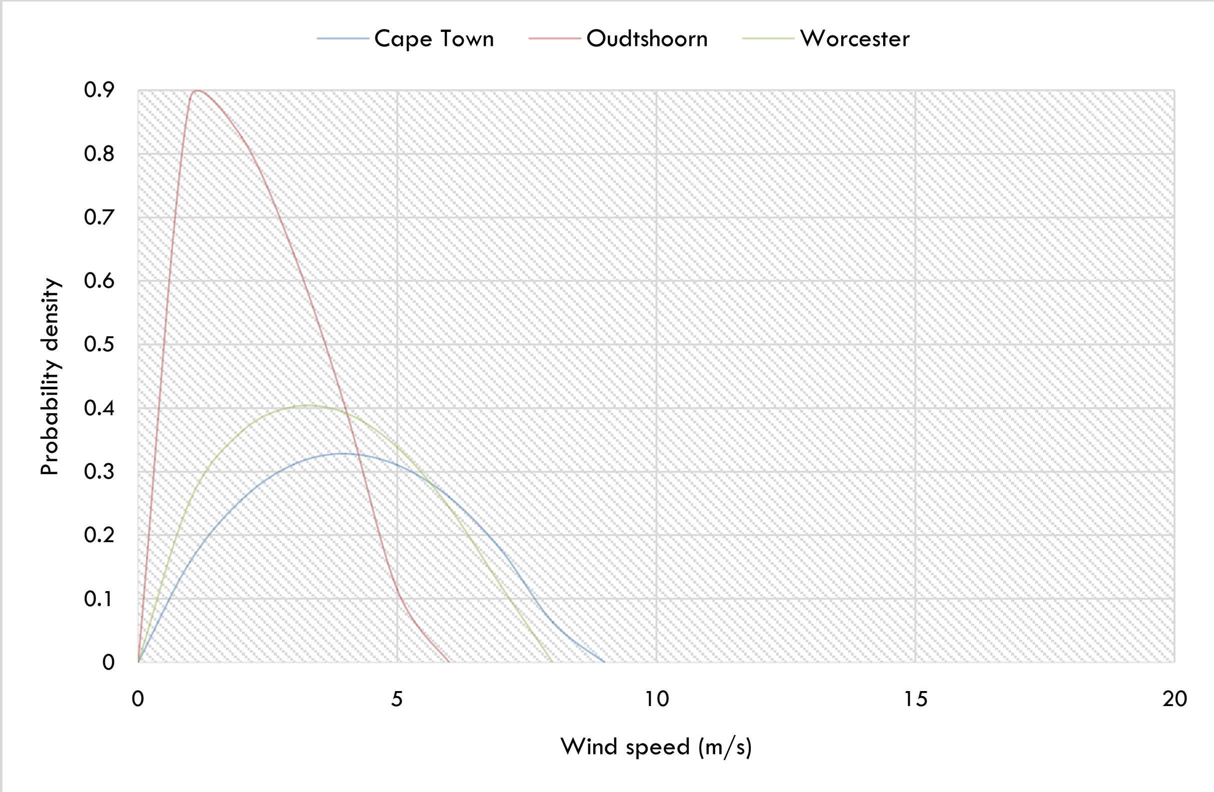

Figure 5-6: Probability distribution for sites in Cape Peninsula region for the whole year (2010 — 2014)

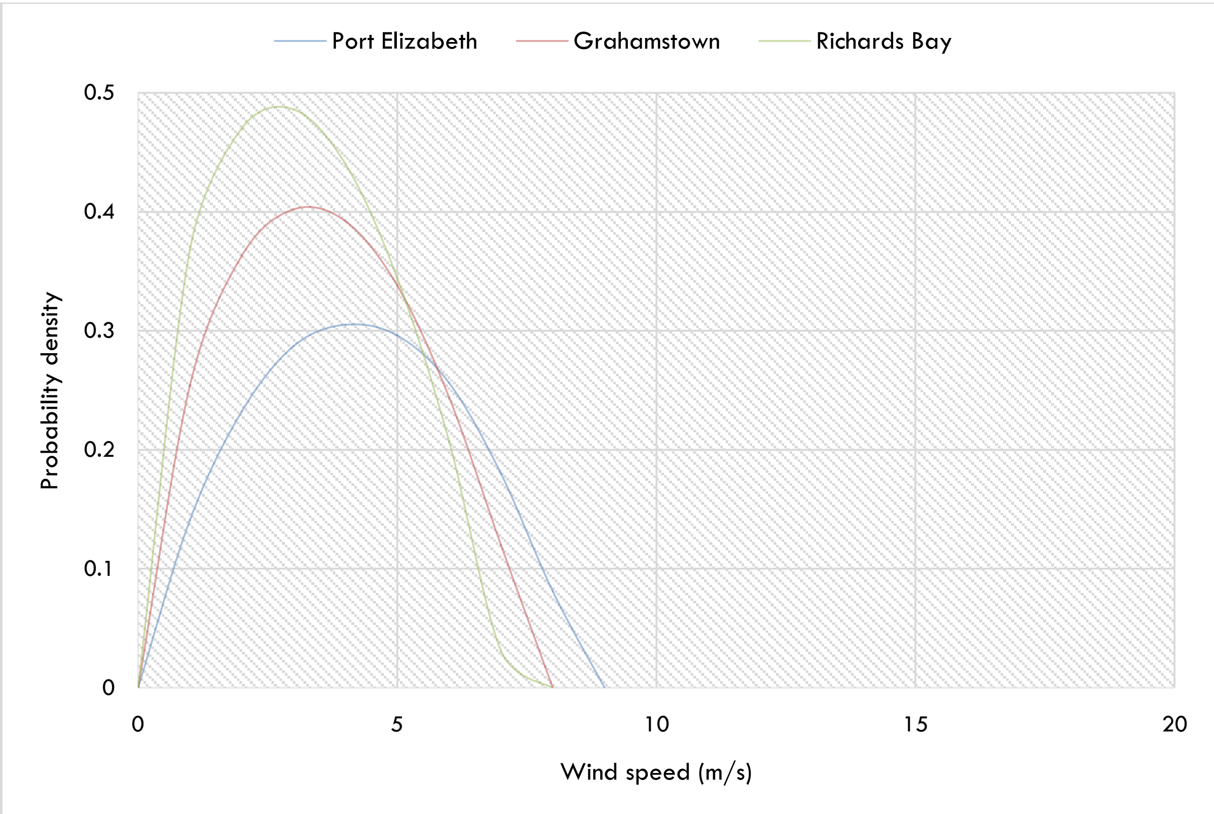

Figure 5-7: Probability distribution for sites in South Eastern region for the whole year (2010 — 2014)

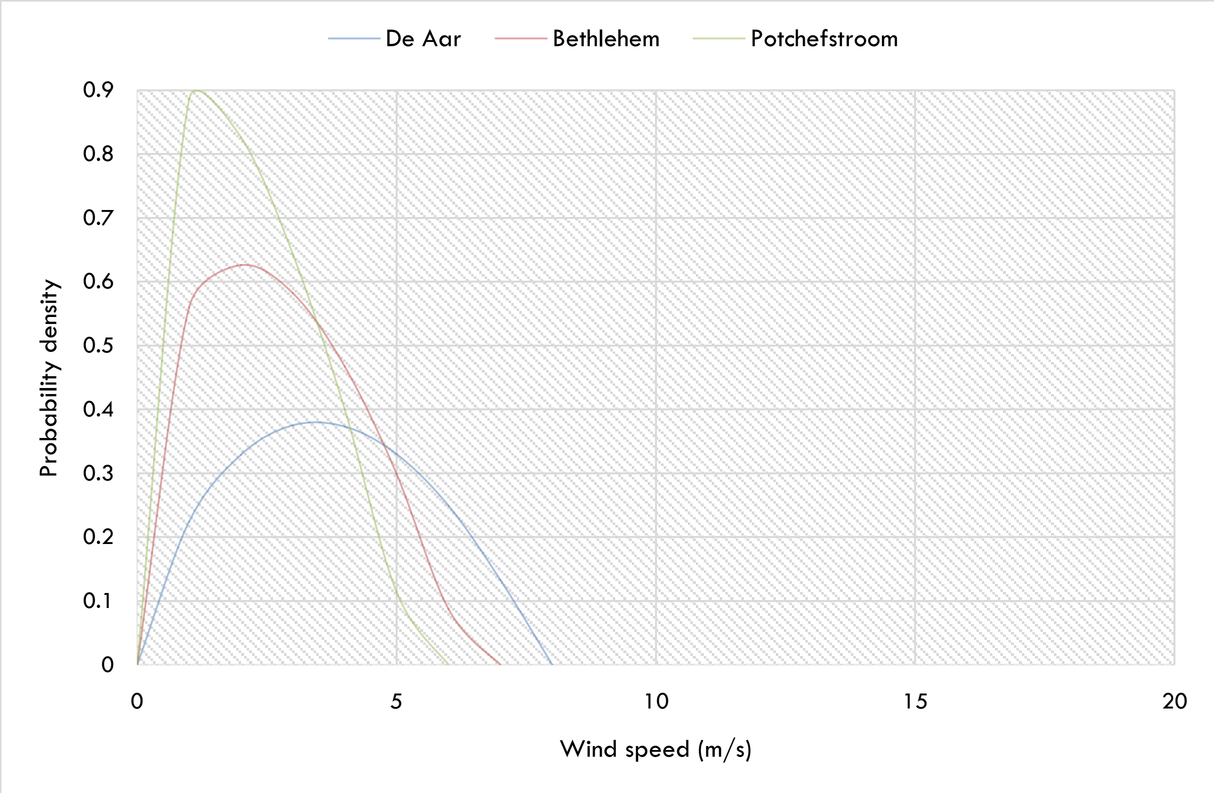

Figure 5-8: Probability distribution for sites in Central region for the whole year (2010 — 2014)

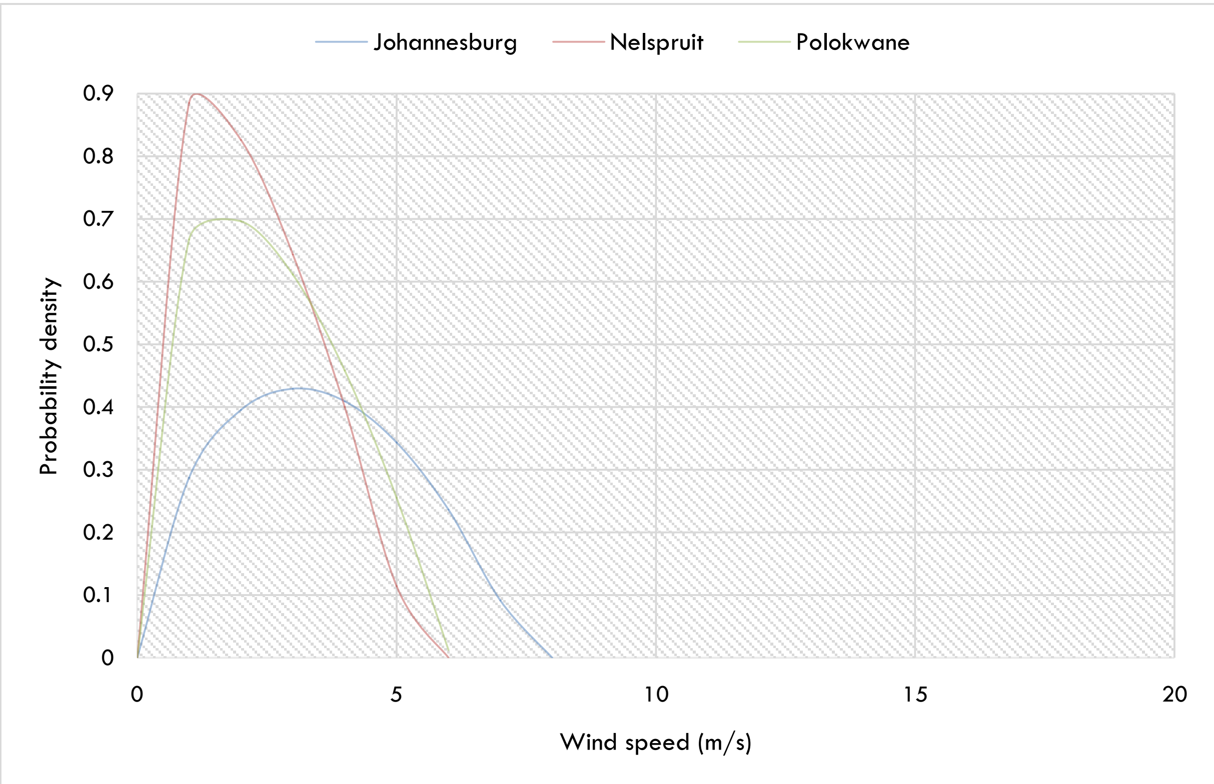

Figure 5-9: Probability distribution for sites in Northern region for the whole year (2010 — 2014)

5.2.2 Energy Generation

The energy yield from a turbine is a function of the wind speed and wind distribution of the site (Ani *et al*., 2013), and this must be considered primarily with regards to the design and operation of a turbine as the probability density distribution of the wind speed significantly affects the performance of the turbine (Gagliano *et al*., 2013). Manufacturers of small wind turbines generally provide rated power at different speeds, as turbines operate in different weather conditions with different wind speeds, thus having different specifications.

For any selected site, the energy yield of a wind turbine can be derived by combining the wind speed data of that particular site with that of the power curves of the selected turbine (Burton *et al*., 2001; Chang & Tu, 2007; Gokcek & Genc, 2009). The wind turbine choice for any given site is determined based on the wind profile of the site (Ayodele *et al*., 2012b). For this study, two commercially available small wind turbines, namely the e300i and the e400n were evaluated for all the considered sites. The technical specifications of the selected turbines are presented in Table 5.3.

Table 5-3: Technical specifications of selected small wind turbines

Characteristics	e300i	e400n
Turbine type	HAWT	HAWT
Number of blades	3	3
Rotor diameter (m)	3	4
Rated power (kW)	1	3.5
Rated wind speed (m/s)	10.5	12
Cut-in speed (m/s)	2.5	4
Cut-out speed (m/s)	—	—

Source: www.kestrelwind.co.za

The e300i and e400n turbine models are three blade rotors designed to power a twin axial flux permanent magnet brushless alternator with good heat management. The turbines are fitted with a patented blade pitch control, therefore they maintain their rated output in excess wind speeds with no cut-out wind speed. The blade pitch control is the system which monitors and adjusts the inclination angle of the blades and thus controls the rotation speed of the blades. At lower wind speeds, the pitching system leads to an acceleration of the hub rotation speed, while at higher speeds, blade pitch control reduces the wind load on the blades and structure of the turbine.

Wind energy is a product of the power generated by a turbine at a wind speed v and time t at an investigated site (Burton *et al*., 2001; Gokcek & Genc, 2009). Thus, the power P generated by the wind, expressed as a function of wind speed, can be calculated by (Manwell *et al*., 2002; Polinder *et al*., 2006; Shawon *et al*., 2013; Ani *et al*., 2013):

$$P = \frac{1}{2} C_p \rho v^3 A \qquad (5)$$

Where ρ is the air density, v is the wind speed, r is the radius of turbine rotor, C_p is the power coefficient of the rotor or the aerodynamic efficiency, $A = \pi r^2$ (swept area of the rotor), and the wind density ρ is assumed to be 1.225 kg/m^3 (Ani *et al*., 2013).

The power coefficient is the ratio between the energy extracted and the wind energy available, and has a Betz limit (maximum value) of 16/27 (Gagliano *et al*., 2013), or this limit is otherwise described as the usable energy of the wind, about 59%, which may be captured by the turbine according to the Betz law (Ani *et al*., 2013). The actual power coefficient, however, is much lower than the Betz limit due to mechanical and electrical losses, thus the actual energy yield of the turbine is less than the usable energy (Ani *et al*., 2013; Gagliano, 2013). Small wind turbines generally have a performance coefficient of less than 40% (Gipe, 2004; EWEA, 2009a).

The captured amount of energy by a turbine is a function the power curve (power output against the wind speed characteristics) of the turbine and the Weibull distribution of the site (Burton *et al*., 2001; Chang & Tu, 2007; Gokcek & Genc, 2009).

Therefore, the energy yield E of a turbine over a time period T is expressed as (Burton *et al*., 2001; Ani *et al*., 2013; Gagliano *et al*., 2013):

$$E = T \int P(v)\, f(v)\, dv \qquad (6)$$

Therefore, when calculating the energy yield for a year, T becomes 8760 hours. Thus, rewriting the equation, the annual energy yield is expressed as:

$$E = 8670 \sum P(v)\, f(v) \tag{7}$$

Applying equation (7) to the power curves of the selected turbines and the wind probability distribution of the sites being considered provides the annual energy yield of the respective small wind turbines in the respective site locations, as presented in Table 5.4. The energy output results are graphically illustrated in Figure 5.10.

Table 5-4: Annual energy production of selected turbines at the different sites

Region	Site Location	e300i (1 kW) (kWh/year)	e400n (3.5 kW) (kWh/year)
Cape Peninsula	Cape Town	2125.18	3316.36
	Oudtshoorn	683.54	239.85
	Worcester	1758.22	2268.66
South Eastern	Port-Elizabeth	2160.69	3432.52
	Grahamstown	1758.22	2268.66
	Richards Bay	1482.19	1557.35
Central	De Aar	1487.79	2358.36
	Bethlehem	1132.49	847.18
	Potchefstroom	683.54	239.85
Northern	Johannesburg	1681.56	2056.58
	Nelspruit	683.54	239.85
	Polokwane	916.47	504.05

From the annual energy production (AEP) calculated, Port Elizabeth demonstrated the highest energy production among all the considered site locations for the two selected turbines. It has annual energy outputs of 2 160.69 kWh/yr. and 3 432.52 kWh/yr. for the e300i (1 kW) and e400n (3.5 kW) respectively, followed by Cape Town with 2 125.18

kWh and 3 316.36 kWh. While Cape Town and Port Elizabeth have the highest annual production in their respective regions, De Aar generated the highest annual energy output in the Central region, and Johannesburg in the Northern region. De Aar exhibited 1 487.79 kWh (e300i) and 2 358.36 kWh (e400n), while the turbines in Johannesburg produced 1 681.56 kWh (e300i) and 2 056.58 kWh (e400n). The least annual energy production in all the sites considered was found in Oudtshoorn, Potchefstroom, and Nelspruit. They all demonstrated the same annual output of 638.54 kWh and 239.85 kWh for the e300i (1 kW) and e400n (3.5 kW) respectively. Interestingly, the turbine with the lower rated capacity, the e300i, seems more suited to sites with low wind speed characteristics than the one with the higher rating, as indicated in the sites with the least annual outputs. The e300i (1 kW) generated a larger annual energy output than the e400n (3 kW) in Oudtshoorn, Bethlehem, Potchefstroom, Nelspruit, and Polokwane.

With the monthly electricity consumption of the majority of low-income households below 50 kWh (600 kWh/year), and an average monthly consumption of 132 kWh (1 584 kWh/year) by households throughout out SA (Prasad, 2006), although expected to rise to approximately 350 kWh monthly (4 200 kWh/year) (Louw *et al*., 2008), the application of SWTs can meet the energy demand of some households in some environments in the country, or can be integrated with hybrid systems in several cases.

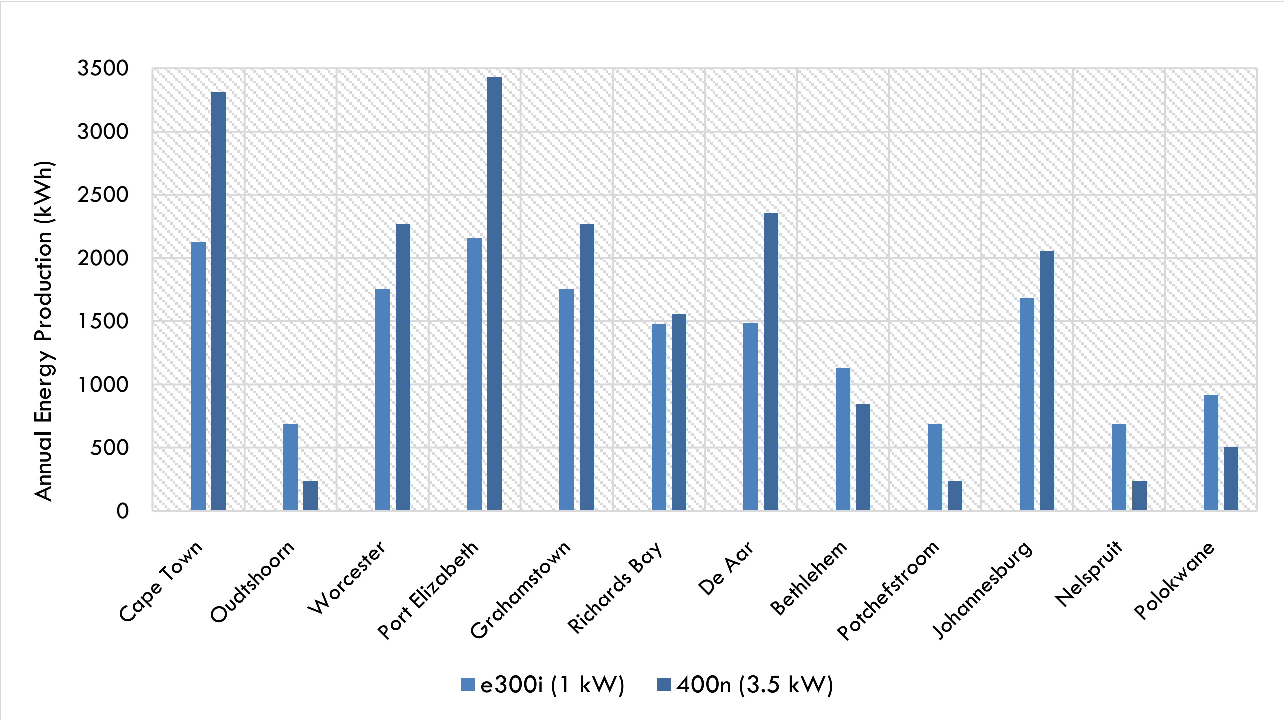

Figure 5-10: Annual Energy Production of selected turbines at the different sites

5.3 Economic Performance

The poor economic performance of renewable technologies, where the avoided cost of purchasing grid electricity is usually unable to repay the capital cost of the technology within its useful lifetime, is the foremost limitation to the mass installation of these technologies (Ayompe, 2011). Analysing the economic viability of micro-generation technologies correctly is essential, as it enables a potential consumer to assess the final outlay and the payback period of such systems (Gagliano *et al*., 2013). This study evaluated the economic performance of the two selected commercially available small wind turbines in the different regions under consideration.

The cost of the electricity generated is the most important input parameter in the investment and economic analysis of electricity generating facilities (Simic *et al*., 2013). If the small wind system can generate at a low cost, then the system has economic viability. However, several factors influence the unit cost of energy (expressed in terms of money per kW) that varies for respective sites in different countries (Gokcek & Genc, 2009). Deriving the cost of wind-generated electricity and assessing its economic viability involve analysing economic parameters such as investment costs, operation and maintenance costs, energy production, turbine lifetime, interest rates, discount rates, etc. (Morthorst, 2004; Gokcek & Genc, 2009; Simic *et al*., 2013). Generally, the unit cost of energy is a fraction of the amount of energy generated of the total expenditures with respect to the given time interval, however, the economic viability of a small-scale generation system can be evaluated by several methods (Ayompe, 2011; Shawon *et al*., 2013).

A few basic economic models for evaluating an electricity generating system were utilised in this study, including: Simple Payback Period (SPP); Net Present Value (NPV); and Levelised Cost of Energy (LCOE), in order to provide a balanced representation (Bishop & Amaratunga, 2008; Gokcek & Genc, 2009; Ayompe, 2011; Simic *et al*., 2013; Shawon *et al*., 2013).

The initial costs (IC) or investment costs of the selected systems for this study include the specific price (capital cost) of the turbine system and the installation costs (Gokcek & Genc, 2009; De Oliveira *et al*., 2011). The specific (capital) costs of the selected systems include the costs of the turbine, stand, and battery, and they are presented in Table 5.5 below

Table 5-5: Capital Costs of selected small wind turbines

SWT model	Rated Capacity (kW)	Specific Cost (ZAR)
e300i	1	30 825
e400n	3.5	72 012

Source: Kestrel Renewable Energy (2015)

The following assumptions were considered for the economic evaluation of the turbines:

1. The small wind energy systems are for off-grid generation.
2. The lifetime of the SWES is assumed to be 20 years (Mostafaeipour, 2013).
3. The installation cost is 30% of the specific cost of the turbine system (Kestrel).
4. The discount rate is considered to be 10%.
5. Operation and maintenance (O&M) is 15% of the initial investment cost.
6. The small wind energy systems are assumed to generate equal amounts of energy outputs per year in its lifetime.
7. The average sales price of electricity in South Africa is R1.53/kWh (CoCT, 2014).

5.3.1 Simple Payback Period (SPP)

The payback period is the time period (generally in years) in which a return is required from an investment or the amount of time it takes for the positive cash flow to exceed the initial investment, without concern for the time value of money (Ayompe 2011; Mostafaeipour, 2013). It is important to know how quickly an investment might pay back, since it is the most straightforward and easiest of all economic models to comprehend by the general public. However, this model's disregard for the timing of cash flow, energy price escalation, and the cash flow beyond the payback period are its main shortcomings (Kaplan, 1983; Ayompe, 2011; Rashford *et al*., 2013). The SPP is an important determinant in investment considerations, as shorter payback periods are normally more desirable (Mostafaeipour, 2013).

The formula for the SPP is presented as (De Oliveira *et al*., 2011; Mostafaeipour, 2013):

$$\text{SPP (years)} = \frac{\text{Initial Cost (R)}}{\text{Average Annual Revenue (AAR)}} \quad (9)$$

$$= \frac{\text{Initial Cost (R)}}{\text{Energy Output } \left(\frac{\text{kWh}}{\text{year}}\right) \times \text{Electricity Price } \left(\frac{\text{R}}{\text{kWh}}\right)} \tag{10}$$

Where initial cost is the total price (Rand) paid for the small wind system and the installation, average annual revenue is based on hourly production, energy output is the amount of energy generated per year by the system, and electricity price is the tariff for energy from the utility (market retail price). The payback periods for the e300i and e400n turbines are presented in Table 5.6.

Table 5-6: The payback period of selected turbines at the different sites

Region	Site Location	e300i (1 kW) (year)	e400n (3.5 kW) (year)
Cape Peninsula	Cape Town	12	18
	Oudtshoorn	38	255
	Worcester	15	27
South Eastern	Port-Elizabeth	12	18
	Grahamstown	15	27
	Richards Bay	18	39
Central	De Aar	18	26
	Bethlehem	23	72
	Potchefstroom	38	255
Northern	Johannesburg	16	30
	Nelspruit	38	255
	Polokwane	29	121

The payback periods for the e300i (1 kW) model are more than the useful lifetime of the turbines in Oudtshoorn, Bethlehem, Potchefstroom, Nelspruit, and Polokwane, hence, the initial investment may not be recovered in these locations before the end of the operating lifetime of 20 years of the turbine. For the e400n (3.5 kW), only Cape Town and Port Elizabeth have payback periods below the lifetime of the system. Cape Town and Port Elizabeth demonstrated the least amount of recovery years in the two categories of turbine models, with approximately 12 years and 18 years for the e300i (1 kW) and e400n (3.5 kW) respectively. The longest recovery years of 38 years and 255 years for the e300i (1 kW) and e400n (3.5 kW) turbine models were recorded in Oudtshoorn, Potchefstroom, and Nelspruit.

5.3.2 Net Present Value (NPV)

The Net Present Value (NPV) is a widely accepted economic method for evaluating investment projects and it applies to the principle of capital value over time (Brealey & Myers, 1997; De Oliveira *et al*., 2011). The NPV operates on a concept of present value and calculates the difference between the present values of cash inflows and the present values of cash outflows, at a given target rate of return or cost of capital (Ayompe, 2011; De Oliveira *et al*., 2011). It is the sum of every discounted cash flow related to an investment project. A project is financially viable if the NPV is positive, while a negative value signifies an investment that is not viable (Brockington, 1993; Ayompe, 2011).

For an energy project, the NPV is termed as the difference between the present value of the benefits and the present value of the costs (De Oliveira *et al*., 2011). There are assumptions that the distribution of wind speed will be constant yearly, leading to an uniform amount of electricity being generated yearly, and that the annual revenue remains will also be uniform (Kaltschmitt, 2007; De Oliveira *et al*., 2011). This cash flow uniform must be discounted, as it is a future occurrence.

The NPV of a uniform cash flow is (Kaltschmitt, 2007; De Oliveira *et al*., 2011):

$$NPV = AAR \left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] - IC \qquad (11)$$

Where AAR is the Average Annual Revenue (based on hourly production), i is the discount rate, n is the lifetime of the turbine, and IC is the Initial Capital Cost (which is the present value of cost). The calculated NPVs for the e300i and e400n turbines are illustrated in Table 5.7.

Table 5-7: The Net Present Value of selected turbines at the different sites

Region	Site Location	e300i (1 kW) (ZAR)	e400n (3.5 kW) (ZAR)
Cape Peninsula	Cape Town	– 12,271.59	– 50,229.54
	Oudtshoorn	– 31,130.24	– 90,478.41
	Worcester	– 17,071.90	– 63,938.61
South Eastern	Port-Elizabeth	– 11,806.98	– 48,713.54
	Grahamstown	– 17,071.90	– 63,938.61
	Richards Bay	– 20,682.74	– 73,243.57
Central	De Aar	– 20,609.46	– 62,765.12
	Bethlehem	– 25,257.33	– 82,533.66
	Potchefstroom	– 31,130.24	– 90,478.41
Northern	Johannesburg	– 18,074.98	– 66,712.83
	Nelspruit	– 31,130.24	– 90,478.41
	Polokwane	– 28,083.27	– 87,022.33

According to the analysis, the two models of small wind turbines selected have a NPV of less than zero for all the sites under study, thus, none of the turbines are economically viable for installation in all the considered sites.

5.3.3 Levelised Cost of Energy (LCOE)

The LCOE is probably the most important model for evaluating the economic performance of power projects such as wind energy (Gokcek & Genc, 2009). The economic model calculates the unit cost of production of electricity over the economic life of the system project or the cost to produce one kWh of electricity, and it includes evaluating the total installation cost, financing costs, return on capital, etc. (Gokcek & Genc, 2009; De Oliveira *et al*., 2011). The result, which is expressed in cost per unit of energy output (e.g. R/kWh), has the interesting ability to create a comparison between different sources of generation (Ayompe, 2011). Furthermore, according to Gross *et al*. (2010), LCOE offers parameters for measuring the motivation for intervention in and informing policy.

The levelised cost for a wind energy system can be calculated as the ratio of the total annualised cost of the system to the annual electricity generated, and is expressed by (Gokcek & Genc, 2009):

$$LCOE = \frac{(IC \times CRF) + O\&M}{Annual\ \ Energy\ \ Production} \quad (13)$$

Where IC is the Initial Cost, $O\&M$ is the annual operations and maintenance cost, and CRF is the Capital Recovery Factor for the system. The Capital Recovery Factor for any given discount rate i and turbine lifetime n is expressed as (Gokcek & Genc, 2009):

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1} \quad (14)$$

The levelised costs analysed in this study for the e300i and e400n turbines in the different site locations considered are presented in Tables 5.8.

Table 5-8: The LCOE of selected turbines at the different sites

Region	Site Location	e300i (1 kW) (R/kWh)	e400n (3.5 kW) (R/kWh)
Cape Peninsula	Cape Town	5.03	7.54
	Oudtshoorn	15.65	104.21
	Worcester	6.08	11.02
South Eastern	Port-Elizabeth	4.95	7.28
	Grahamstown	6.08	11.02
	Richards Bay	7.22	16.05
Central	De Aar	7.19	10.59
	Bethlehem	9.45	29.50
	Potchefstroom	15.65	104.21
Northern	Johannesburg	6.36	12.15
	Nelspruit	15.65	104.21
	Polokwane	11.67	49.59

From the analysis, the LCOE of the two turbine models for all the sites considered are neither cost-competitive nor economically viable when compared with the electricity tariff offered by the national electricity provider, Eskom. These uncompetitive high costs of electricity ranged between R4.95/kWh and R15.65/kWh for the e300i (1 kW) model, and R7.28/kWh and R104.21/kWh for the e400n (3.5 kW) model, as against the R1.53/kWh (CoCT, 2014) of the conventional generation. The lowest costs were evident in Port Elizabeth, while the highest costs were found in Oudtshoorn, Bethlehem, Potchefstroom, Nelspruit, and Polokwane in the two categories of turbines. Cape Town has the lowest electricity costs in the Cape Peninsula region, De Aar in the Central region, and Johannesburg in the Northern region.

5.4 Environmental Value

The costs estimated for the selected turbine systems in the different sites in the previous sections did not take into consideration the environmental impact. However, this factor is imperative, particularly if costs are being compared between fossil fuel generations and renewable energy. In accounting for the environmental loss when generating by conventional sources, an additional cost termed external cost or externality is included in the cost estimation (Shawon *et al*., 2013).

According to the European Commission (1994), externalities are benefits and costs which arise when the social or economic activities of one group of people have an impact on another. Analysing external costs involves the economic valuation of the environmental and health costs of a particular source of electricity generation. Externalities help to estimate the hidden benefits/damages of electricity production not accounted for in the existing pricing system, and also establish a fair comparison of the different electricity production activities, as all costs to society, both internal and external, need to be taken into account (EWEA, 2009a). These costs are borne by tax-payers, including consumers and non-consumers of conventional generation and future generation, and they include the influence on human health, climate change, ecological impacts, subsidies, etc. (Shawon *et al*., 2013).

Determining the external cost of a generating system is fairly complex. The unit charge of this cost (R/kW h) is derived by multiplying the unit energy input (R/kJ) and heat rate (kJ/kW h) of different power plants (Shawon *et al*., 2013). Similarly, EcoSense, a computer model for assessing environmental impacts and the resulting external costs of electric power generation systems, can be used to model the emissions of the coal generation (EWEA, 2009a). To run the model, the capacity, full load hours of operation, the volume stream of exhaust gas per hour of the coal generation or fossil fuel plants, and the damages by air pollutants (CO_2, SO_2, NO_X) from the fossil fuel are valued by the model, and then added together to get the external costs (EWEA, 2009a).

The economic evaluation showed poor investment returns, however small wind turbines are still being considered in the country by consumers for environmental sustainability, corporate social responsibility, and partial energy independence (Altman *et al*., 2010; Payne, 2014; Pederson, 2014). Small wind turbines have been in use for water pumping for many years with approximately 270 000 existing wind turbines in South Africa (Altman *et al*., 2010). Furthermore, some wind turbines were installed in the Mandela School of Science and Technology, Eastern Cape by Siemens South Africa, mainly for corporate social responsibility and green energy promotion, rather than economic viability (Pederson, 2014).

The determination of the external costs of coal generation and small wind energy systems in South Africa allows the environmental benefits of the small wind systems to be expressed in economic terms, hence, making them fairly competitive. Although electricity generated by small wind turbines reduces the emission of GHGs, a very small amount of GHG reduction is actually realised when looking at the relatively low energy outputs of the two turbines analysed, thus, low environmental performance is achieved.

5.5 Conclusion

The technology performance sub-hypothesis for this research study was tested in this chapter by evaluating and establishing the effects of the technology performance of small wind energy systems on the viability and future growth of the sector in South Africa. These sub-hypotheses are:

Sub-Hypothesis H_1: The viability and future growth of the small wind sector in South Africa is limited by the technology performance of the systems.

Sub-Hypothesis H_0: The viability and future growth of the small wind sector in South Africa is not limited by the technology performance of the systems.

The results from the evaluation of the technology performance of small wind energy systems in South Africa were derived from an analysis of the techno-economic performance of the systems. The wind characteristics of twelve different geographic locations in the country were initially analysed. Based on this, two commercially available small wind turbines [the e300i (1 kW) and e400n (3.5 kW) models] were selected in order to evaluate their energy yield and economic viability in these considered sites. The following conclusions were drawn after analysing the results:

- The wind speed characteristics and distribution of the sites analysed using the Weibull mathematical model and the hourly measured long-term wind speed data (2010 – 2014) at a height of 10m AGL showed that Port Elizabeth is the windiest site, while Oudtshoorn, Potchefstroom, and Nelspruit (remarkably sharing the same Weibull parameters and distributions) represented the least windy sites. The probability of observing higher wind speeds is the greatest in Port Elizabeth, followed by Cape Town. This study confirmed that the South Eastern and Cape Peninsula regions have higher probabilities of observing high wind speed in South Africa than any other regions.
- In the energy yield analysis for all the sites considered, Port Elizabeth produced the highest annual energy output for the two selected turbine models at 2 160.69 kWh and 3 432.52 kWh for the e300i (1 kW) and e400n (3.5 kW) respectively. The least AEPs were in Oudtshoorn, Potchefstroom, and Nelspruit at 638.54 kWh and 239.85 kWh for the e300i (1 kW) and e400n (3.5 kW) respectively. Interestingly, the turbine with the lower rated capacity seems more suited for sites with low wind speed characteristics than the one with a higher rating. The e300i (1 kW) generated a larger annual energy output than the e400n (3 kW) in Oudtshoorn, Bethlehem, Potchefstroom, Nelspruit, and Polokwane.
- Importantly, with a monthly electricity demand below 50 kWh (600 kWh/year) by the majority of low-income households, and an average monthly consumption of 132 kWh (1 584 kWh/year) by households in South Africa (Prasad, 2006), although expected to rise to approximately 350 kWh monthly (4 200 kWh/year) (Louw *et al*., 2008), the installation of small wind turbines can meet the energy demand of a few households in some environments in the country, or it can be integrated with hybrid systems in most cases.

- The economic evaluation of the viability of the installation of the turbines in all the sites under study involved the application of different basic economic models for evaluating the electricity generating system including: Simple Payback Period (SPP); Net Present Value (NPV); and Levelised Cost of Energy (LCOE), so as to provide a balanced representation.
- The SPPs for the e300i (1 kW) model are less than the useful life of the turbines in almost all the locations considered except Oudtshoorn, Bethlehem, Potchefstroom, Nelspruit, and Polokwane, hence, the initial investment may not be paid back in these mentioned locations before the turbine retires in 20 years. Only Cape Town and Port Elizabeth have SPPs that do not exceed the useful lifetime of the system for the e400n (3.5 kW). The least recovery years (exhibited by Cape Town and Port Elizabeth) for both turbines in all sites considered are 12 years and 18 years for the e300i (1 kW) and e400n (3.5 kW) respectively.
- In the NPV analysis, the two turbine models evaluated have NPVs of less than zero in all the sites considered, thus, none of the turbines may be economically viable for investment in all the considered sites.
- For the Levelised Cost of Energy economic evaluation, the costs of electricity calculated for the two turbine models in all the sites considered are high and uncompetitive when compared with the average tariff of R 1.53/kWh offered by the national electricity provider, Eskom. The least costs for electricity was found in Port Elizabeth and are R4.95 kWh and R7.28 kWh for the e300i (1 kW) and e400n (3.5 kW) turbine models respectively.
- The economic evaluation results revealed that SWT are yet to be economically viable in South Africa under the present policies and assumptions considered. As demonstrated by this study, the low energy yield, high investment costs (compared to the value of the electricity produced), relatively low Eskom tariff and uncompetitive LCOE of the systems, are still major limitations.
- The application of external cost to the different costs of energy estimated for the selected turbines can make them more competitive with conventional generation. Although GHG emissions are reduced by small wind generations, low environmental value is added or actually realised with regards to the low energy outputs of the two turbines evaluated in this study.

- While the economic viability of small wind generation as measured against the Eskom tariff is weak, some consumers in the country still install SWTs to supply an often small fraction of their energy needs, for environmental sustainability, and as part of their corporate social responsibility. These consumers include the people that have applied turbines for water pumping in the country and the installations at the Mandela School of Science and Technology, Eastern Cape by Siemens South Africa to demonstrate more of a corporate social responsibility and green energy promotion rather than economic viability.

The results established that the technology performance of the systems in the country is poor under the available policies and assumptions. All the success criteria for the technology performance sub-hypothesis were met by the research results. Hence, the *Sub-Hypothesis* H_1 is fulfilled, that, the viability and future growth of the small wind sector in South Africa is limited by the technology performance of the systems.

Thus, the identified and established technology performance limitations for small wind energy systems in South Africa include:

- High investment costs
- Uncompetitive LCOE
- Absence of a long-term technology development plan/path to sustainable growth

The analyses and projections made in this chapter are based on data collected from public documents, related literature and industry professionals. Validating the data offered by the wind manufacturers is hard and the degree of co-operation differs between respective firms. Collaborative efforts among stakeholders would greatly improve these shortcomings. Furthermore, the wind speed data used for this study were measured at 10m AGL, which represents a “least height” scenario. Measuring at a higher height may increase the energy yields, which will be an added advantage to the consumer. The installation of a wind turbine on a tower should be at least 9 m (Refocus, 2002). While new and up-to-date data could change specific numbers in the study, the overall message of the study would not change. The proposed development path to the viability and further growth of the small wind sector is presented in the next chapter.

CHAPTER 6

DEVELOPMENT PATH TO VIABILITY AND SUSTAINABLE GROWTH

6.1 Introduction

The two sub-hypotheses (policy and technology performance) propagated were tested and confirmed in the previous chapters. Considering that all the success criteria for the two sub-hypotheses have been supported by the research results, the main *Hypothesis* H_1 is consequently established (partly) that: *the viability and future growth of the small wind sector in South Africa is limited by the presently available policies benefitting the systems and technology performance of the systems*. Accordingly, *the viability and future growth of the small wind sector in South Africa therefore requires a sustainable alternative development path to overcome the limitations identified*.

As revealed by the study, the limitations to the viability and future growth of the sector which the proposed alternative development path seeks to overcome include:

- Insufficient financial incentives
- Policy uncertainty
- Poor administrative processes
- High investment costs
- Uncompetitive LCOE
- Absence of a plan/path to a free competitive market and sustainable development

The installed capacity growth of the systems remains restricted until cost reduction and/or support policies increase commercial viability (Jamasb & Kohler, 2007). The political structure of any nation has a huge influence on whether small wind systems are utilised and accepted in the country. In most countries, the systems are not economically fully viable without government intervention (Bird *et al*., 2005; Rickerson *et al*., 2007). Globally, local markets for small wind generation systems have been boosted by the provision of incentive supports. The introduction of more financial support programs is required for the small wind sector in South Africa, due to the potential these incentives have in advancing the development and deployment of the systems in the country. However, the sector needs to attain self-sustainability which will ensure a continued and sustained growth. There is need for the industry to be transformed from a place of high initial costs and negligible deployment, to a sector with lower initial costs and bigger market shares (Parker, 2008; Ayompe, 2011). In pursuing these, the proposed alternative development path presents two growth paths termed the advanced-growth and moderate-growth development path.

The advanced-growth development path is incentive-driven, and is designed as a near-term solution to address the limitations revealed by this research study. These limitations include insufficient financial incentives, policy uncertainty, poor administrative processes, and also temporarily, the high investment costs of the systems. The moderate-growth path is cost-competitive, and a long-term solution that will lead to economic viability, a free market, and sustainable growth of the sector, while addressing the limitations of high investment cost and an uncompetitive LCOE. These two growth paths are developed on the premise that all the stakeholders in the country's small wind sector need to learn from and build on the experiences of those nations in the world that have successfully demonstrated a sustained free market environment for small-scale generation.

6.2 Advanced-Growth Development Path: Market-Pull

The advanced-growth development path is built on the assumption that the continuous provision of new and existing market-pull support policies for the small wind sector in the country will quickly grow the market and realise an increase in installed capacity. This path, which relies primarily on financial incentive programs, is developed only as a temporary support measure, but it is needed to institute an established and positive commercial environment. It is a near-term solution that addresses the limitations of insufficient financial incentives and policy uncertainty, and provides a temporary solution to high investment costs.

This thesis emphasises that the level of financial support emanating from the regulatory environment and the financial ability to install small wind systems are pivotal to kick-start the rapid development of the market. Several policies have been applied in different jurisdictions to advance the uptake of small-scale generation, however, this study proposes a tested investment capital subsidy tool for the quick growth of this sector. The feed-in tariff for the small wind sector in South Africa was not considered by this thesis, as the generated energy yield by the two turbines analysed in all the considered locations is barely enough to meet the demand of the consumers, and thus, they will not be able to feed the grid.

This path describes a situation in which consumers of small wind systems are assisted with investment subsidies in form of capital cost grants or loans, to successfully address the limitations posed by up-front cost, which are a big threat to small wind deployment. The subsidy can be provided per kW of turbine rating or as a percentage of the investment cost (Wohlgemuth & Madlener, 2000). Investment subsidies are financial incentives frequently used by the government to reduce or overcome the high capital costs or initial investments encountered by investors or project developers that encourage investment in renewable technology (Wohlgemuth & Madlener, 2000; Van Dijk *et al*., 2003). The sales of less economical renewable technologies are usually stimulated by these subsidies, and they generally account for between 20% and 50% of the investment or capital cost (Van Dijk *et al*., 2003). These subsidies are from the country's tax fund or a surcharge on the bills of utility consumers and generally provided to consumers by the government (Wohlgemuth & Madlener, 2000).

The first two limitations to the viability and growth of the small wind system in South Africa as revealed by this study are: insufficient financial incentives and policy uncertainty. Thus, in addressing these limitations, this near-term development path analyses and determines the amount of capital subsidy that can be offered to consumers located at the different sites selected in the study, the operational period of the policy to ensure policy certainty, and the growth projection under this path. The research study assumes that the direct capital subsidy proposed will be provided to the consumers of small wind systems at the time of initial investment.

6.2.1 Estimated Capital Subsidy

The amount of investment subsidies for consumers was estimated using per kW of the rated capacity approach by Ragheb (2015), which uses the investment cost of generation.

Considering the following assumptions:

1. The depreciation period of a conventional power plant (oil, coal or natural gas) is 20 years (Ragheb, 2015).
2. The capacity factor of the installed capacity of a power plant is assumed as 70%.
3. The investment per kW of installed capacity is R26 370 per kW (4 764 MW Medupi Power Project) (AfDB, 2009).

Each kW of the installed capacity of plant generates 365 × 24 × 0.70 = 6 132 kWh/yr.

Thus, the investment per kWh per year is (26 370 R/kW) / (6 132 kWh/yr) = R4.30/kWh.

Considering the two small wind turbines, the e300i (1 kW) and e400n (3.5 kW), analysed by this study for Port Elizabeth (for example):

The annual energy output for the e300i (1 kW) and e400n (3.5 kW) are 2 160.69 kWh/yr and 3 432.52 kWh/yr (each kW delivers 980 kWh/yr) respectively.

The investment per kW of installed capacity is R30,825 for the e300i (1 kW) and R20,575 (R72,012 as a whole) for the e400n (3.5 kW). Thus, the investment per kWh per year for the e300i (1 kW) and e400n (3.5 kW) are R14.27/kWh and R 20.99/kWh respectively.

The financial burden of the two selected small wind turbines to that of the conventional power plant are thus:

for the e300i (1 kW): (R 4.30/kWh) / (R 14.27/kWh) = 0.30

for the e400n (3.5 kW): (R 4.30/kWh) / (R 20.99/kWh) = 0.21

Thus, 30% and 21% of the investment costs of the e300i (1 kW) and e400n (3.5 kW) turbine models can be provided as direct capital subsidies for the consumers.

Furthermore, applying the above approach to all the selected locations, the amount of capital subsidy that can be provided for consumers in Cape Town, Oudtshoorn, Worcester, Port Elizabeth, Grahamstown, Richards Bay, De Aar, Bethlehem, Potchefstroom, Johannesburg, Nelspruit, and Polokwane were computed in Table 6.1.

Table 6-1: Proposed percentage of investment costs to be given as capital subsidies

Region	Site Location	e300i (1 kW) (%)	e400n (3.5 kW) (%)
Cape Peninsula	Cape Town	30	20
	Oudtshoorn	10	1
	Worcester	25	14
South Eastern	Port-Elizabeth	30	21
	Grahamstown	25	14
	Richards Bay	21	9
Central	De Aar	21	14
	Bethlehem	16	5
	Potchefstroom	10	1
Northern	Johannesburg	23	12
	Nelspruit	10	1
	Polokwane	13	3

From these results, the study showed that locations such as Oudtshoorn, Bethlehem, Potchefstroom, Nelspruit, and Polokwane, with relatively low energy yields (higher LCOE) when compared to the other selected locations, might be exempted from the subsidy program, as it will cost more to fund such locations due to their very low productive capacity. Furthermore, the percentage capital subsidies proposed against the different LCOEs in the different locations of the country are graphically illustrated in Figure 6.1 and 6.2 for the e300i (1 kW) and e400n (3.5 kW) models respectively.

The advanced-growth path proposed that the government provides these financial incentives from the general tax fund, a surcharge on the bills of utility consumers, or present uneven support to Eskom. However, there must be thorough control to check for the abuse and false inflation of project costs, and subsidy funds must be allocated judiciously, efficiently, and effectively to deserving consumers.

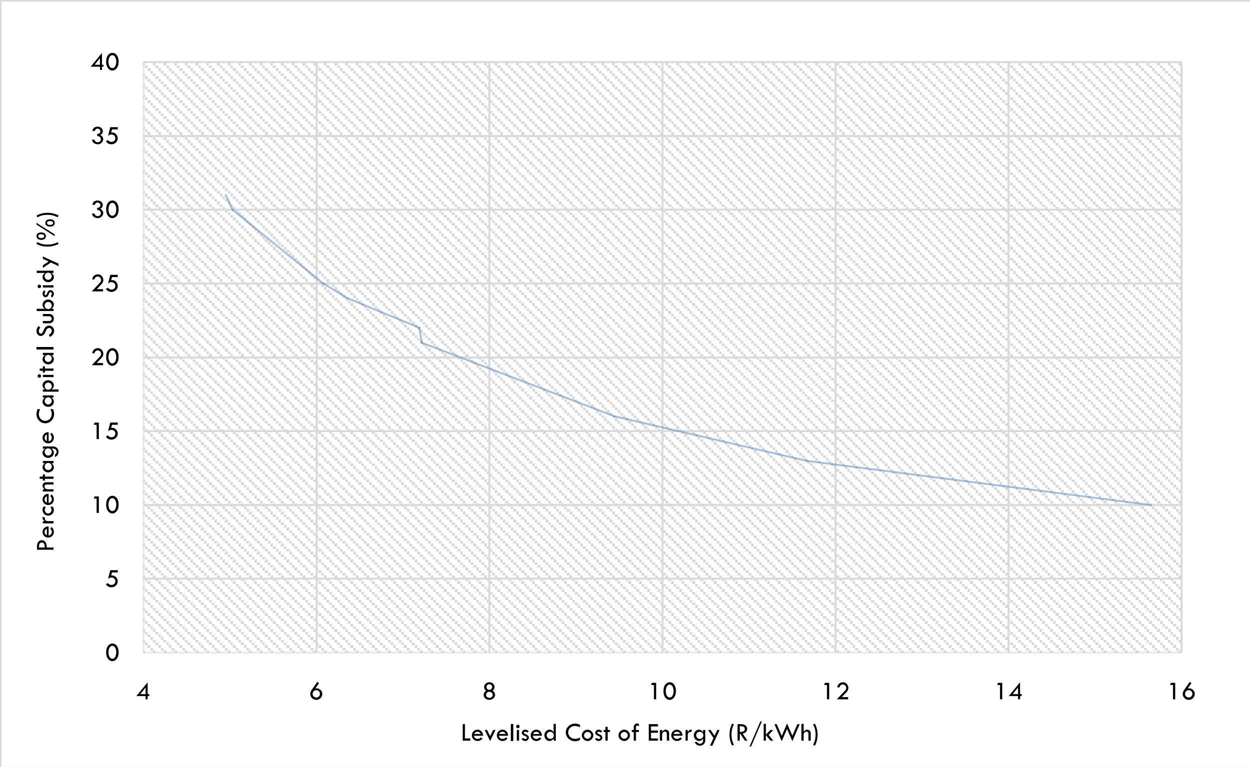

Figure 6-1: Percentage capital subsidy proposed for different LCOEs for e300i (1 kW)

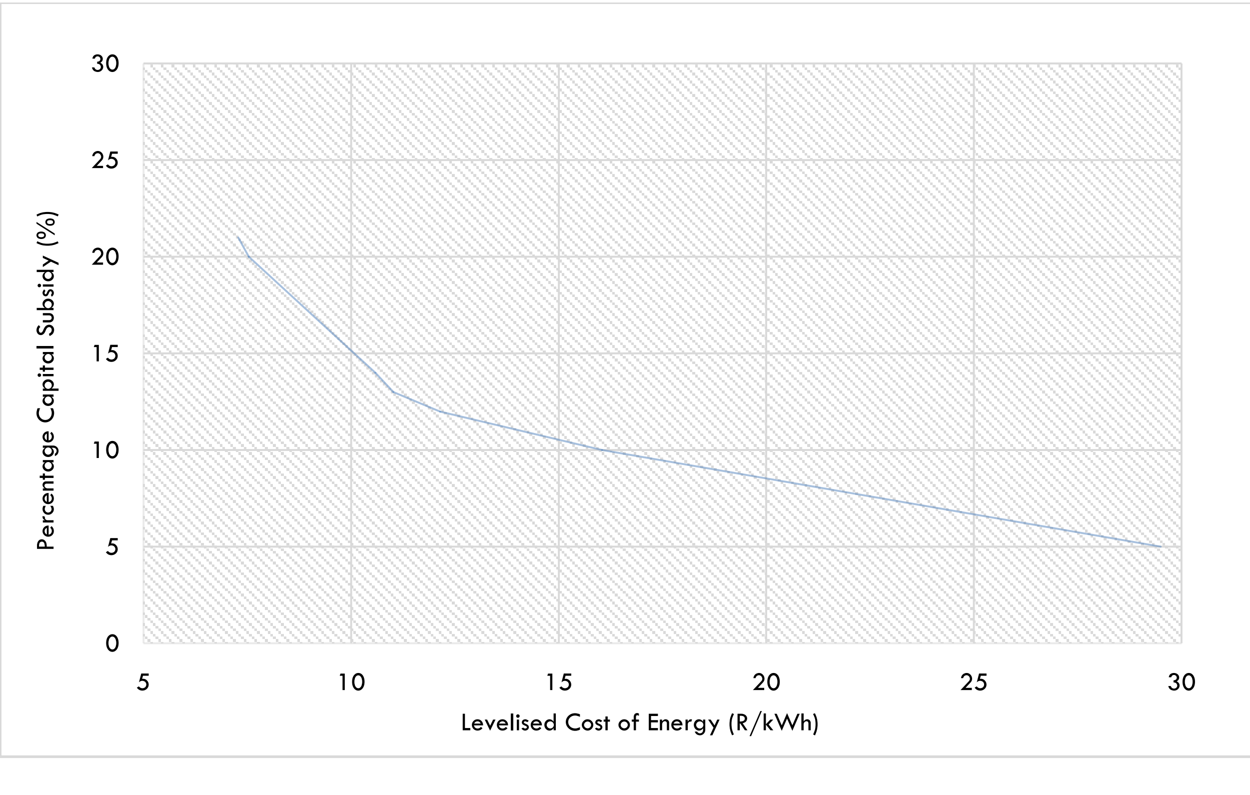

Figure 6-2: Percentage capital subsidy proposed for different LCOEs for e400n (3.5 kW)

The graphical representations demonstrated that, as the LCOEs increase, the level of support from the capital subsidy decreases, which is logical, since it would be economically ill-advised to support locations with relatively low energy yields (highly unproductive) with so much funding. The study supports the premise that low financial incentives for small wind generation in relatively unproductive locations will naturally discourage unproductive investments.

6.2.2 Policy Stability and Growth Projection

Support policies and commitment from the government are essential to the development and deployment of small wind technologies. However, the enactment and implementation of such ambitious policies is not an easy political task (Stokes, 2013). While the level of government financial support for the system is important, the uncertainty and instability of funding may complicate development and investment in the small wind sector. The certainty of a policy greatly impact decision making, risk and opportunity assessment, and cost-benefit analysis, particularly for new investments (Marcus, 1981; Liang & Fiorino, 2013). It is expected that policy certainty will positively affect innovative activities in renewable energy, as this eases the risks attached to decision irreversibility, high investment costs, and long planning time frame (Anadon & Holdren, 2009; Goel & Ram, 2000; Popp, 2010).

The investment subsidy proposed by this development path is compensation for the technological risks associated with the innovative and emerging nature of small wind technology and market risks associated with their high capital cost and demand. It is directed at gradually relieving the burden of high investment cost and high LCOE for the investors or consumers, as the small wind technology gradually matures and become cost-competitive in South Africa. However, this policy tool can become a risk in itself when policy uncertainty is present, hence policy uncertainty needs to be avoided.

The advanced-growth development path is analysed for an operational period from 2016 to 2030, and the investment subsidy program will be granted at the inception of the project. In the first five years (2016 – 2020) of the fifteen-year period analysed, both policy certainty must be ensured and adaptive policy management (preventing rigidity of policy) must be enabled. After the first five years, the policy should continue for the period from 2021 to 2030, but reviewed annually to reflect on or adapt to reductions in the capital costs of technology and LCOE due to the learning effect (which will be discussed further in the moderate-growth scenario). This annual revision should also include investigations of increasing capacity and other market forces, but must not be vulnerable to budget limitations or changed political priorities. The reduction in the amount of subsidy granted or the gradual winding down of the policy program over time should be subjected to the gradual cost reduction of the technology. Policy designs that enable adaptation when high deployment of the technologies occur, may ensure limitations in costs, increase stability of the policy, and create greater political acceptance, or else, they may be attacked by opposition groups (Stokes, 2013).

The success of any policy tool is measured by the ability to achieve the required effect, which in the case of this study implies an increased amount of installed or generated capacity (Van Dijk *et al*., 2003). The introduction of the investment subsidy is expected to bring about an accelerated increase in installed capacity during the period the policy program will be in operation. From the present installed capacity of 0.56 MW (Szewczuk, 2012), the advanced-growth path assumes projections of average growth rates of 35%, 30%, and 25% for the periods from 2016 to 2020, from 2021 to 2025, and from 2026 to 2030 respectively as illustrated by Figure 6.3 depicting the cumulative installed capacity for SWT . The projection is based on the contributions from industry professionals, the historical growth trend of the small-scale wind industry, and the growth pattern of the solar PV industry (which shared some characteristics with the small wind industry) over the past years supported with such a policy (Greenpeace & EPIA, 2011; Gsanger & Pitteloud, 2014). The projection is also based on the assumption that the subsidy proposed will be strengthened and supported by simplified and cost-effective administrative measures, marketing, public awareness, and policy stability. For analytical simplicity, this projection assumed that no new capacity of small wind generation had been added till 2015. By 2030, the expected installed capacity of small wind generation should increase to about 28 MW if adhering to the advanced-growth development path.

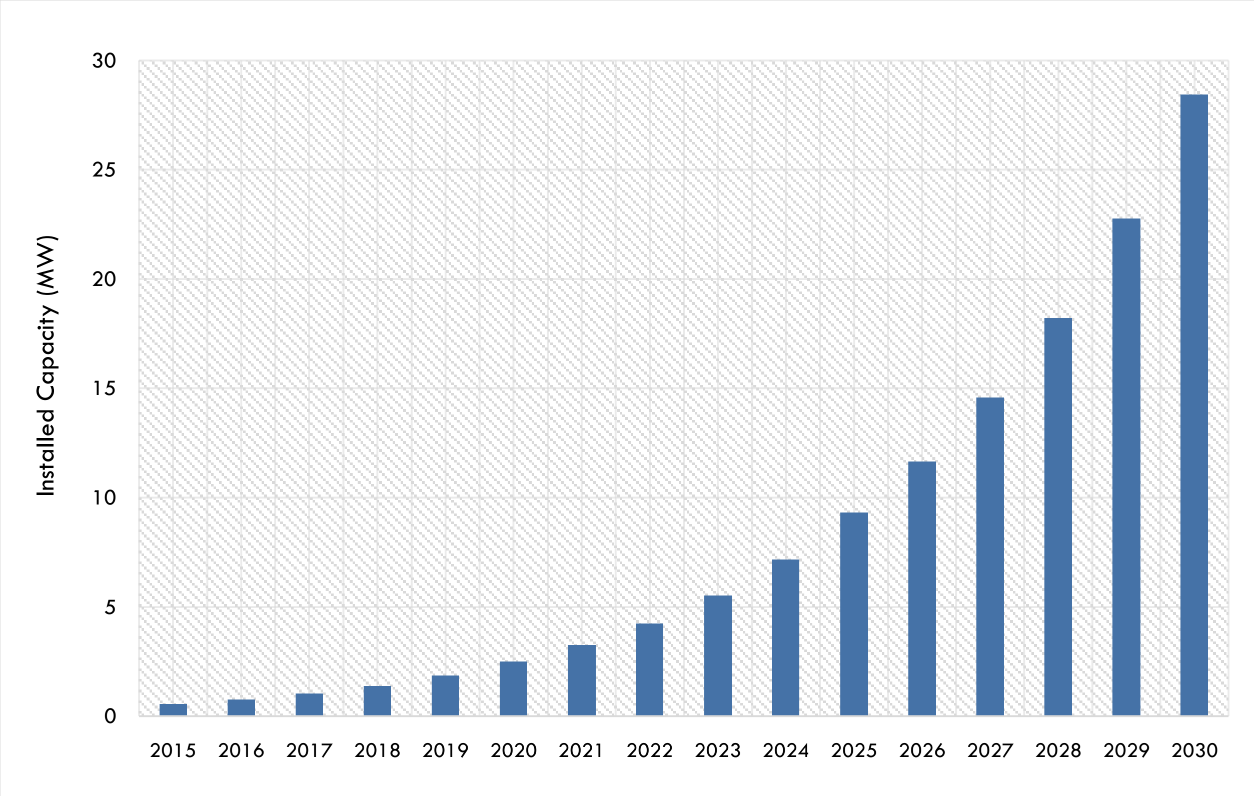

Figure 6-3: Projected cumulative installed capacity under the advanced-growth path

6.2.3 Administrative Processes

Cumbersome administrative processes forms part of the limitations to the viability and further growth of the small wind sector in South Africa, as established by this study. These include permitting, approval, bidding, and other administrative processes filled with delays and bureaucracy; limited technical capacity and shortage of skills; the lack of a nationwide regulatory framework for connecting small-scale wind projects to distribution networks; cross tariff-year arbitrage, tax implications, etc. (Frost *et al*., 2013; Fritz, 2013; Jones, 2014; Lyons, 2014; Milazi, 2015). These limitations contributed to unplanned extended costs, market uncertainty, and a low implementation of the technology (Frost & Sullivan *et al,* 2013).

In bringing the project costs of installations down through administrative processes:

- The study proposed the need for policymakers to introduce administrative processes that are simplified, transparent, clear-cut, linear in approval, and cost-effective for end-users. Administrative delays, bureaucracy, or a long set of requirements requiring end-users to visit multiple government departments or agencies elongates the lead time and increase the cost of new installations.

- Every application with regard to approval, licensing, and certification needs to be evaluated and processed in a one stop-shop arrangement. Short administrative lead times reduce the cost expended on installation and increase the attractiveness of small wind projects, and therefore, this arrangement must be a priority.
- Capacity building for related government departments, agencies and municipal authorities to utilise the abovementioned arrangement and the provision of current information and regulations are equally essential. Similarly, the policy design should seriously consider criteria like corruption and low remunerations in order to avoid limitations to mass deployment.
- The installation of small wind turbines in academic institutions, public facilities, and selected neighbourhoods in townships and cities to educate people about their operation and benefits and create more public awareness for residential and community wind options is required. These proposed initiatives can be an opportunity for the government to boost public interest and involvement in voluntary green energy initiatives and locally advertise governments' contribution to renewable energy development.

6.3 Moderate-Growth Development Path: Technology-Push

The moderate-growth development path proposes the viability and sustainable growth of small wind systems in the context of a reduced level of political interference. This path is aimed at long-term sustainable development in which the small wind system needs to rely on improving its economic performance in order to be less needy of market-pull incentive supports for sustenance in future, but to rely on technology push policies. Technology push policies are support policies for research and development (R&D), learning effect, etc., which will increase performance efficiency and reduce costs (Kimura & Suzuki, 2006), aiding related stakeholders in managing the transition of the sector to a market-oriented one. An economic environment in which subsidies are completely eliminated is plausible and must be supported as this reduces costs borne by taxpayers and sustains the efficiency in the operation of the free market (Burnett, 2015). According to Loris (2014), the competitive procedure that correctly allocates risks and rewards in a free market is circumvented whenever the government tries to drive technological commercialisation. Furthermore, the funding of government-supported projects by the removal of capital from the private sector generates a reliance on the taxpayer which may impede innovation in the long run.

For self-sustainability of the small wind system or realisation of a long-term sustainable development of the small wind sector, the path proposes the establishment of technology-push policies and cost-competitive incentive mechanisms that will encourage cost reduction of the technology, as market-driven policies advance the efficiency of the economy by enabling market forces to regulate demand and supply. Subsequently a market price develops, that is competitive and without or with little government control (Burnett, 2015). Small wind energy systems in South Africa will become competitive and economically viable when the investment cost of the system is reduced and the LCOE is at par with the electricity tariff from Eskom, the national electricity provider in the country.

This research study revealed the limitations to the economic viability of small wind systems to include high investment costs and uncompetitive LCOEs. Thus, in finding solutions to these limitations, the moderate-growth path proposes cost reduction mechanisms for small wind systems to become viable and competitive; and computed the cost projections for the systems toward a free and sustainable market.

6.3.1 The Free Market Theory

There was a significant change in the definition of the state's role and responsibilities in economic activities between 1970 and 2000, with the accusation that the state caused problems in the management of the economy rather than solving them (Backhouse, 2005). There was an extension of market roles and a minimisation of state-controlled and funded activities. When assets are owned by private entities and markets can encourage the competitiveness of prices for goods and services, the free market was efficient, thus, leading to several governments removing regulations, privatising state-owned industries, and building competitive markets (Backhouse, 2005).

A free market economy describes a system in which the economy or market is regulated and influenced by demand and supply (Grigg, 2011). However, no market is completely free, as several limitations and unwanted outcomes accompanying the market system necessitate an active but limited role or input by the government (Grigg, 2011). Examples of such competitive markets are the competitive systems designed by the US to trade permits for sulphur di-oxide emissions, demonstrating greater efficiency than the initial regulations enacted to limit power stations emitting the substance (Backhouse, 2005).

Competition is a very important characteristic of the free market economy. This market limits and discourages economic power abuse by a single entity, as every competitor in a particular market strive to further their individual self-interest (Grigg, 2011). In a free market, all producers or sellers are fighting to win customers, as the individual power of the producers is displaced by competition between them, resulting in less corruption in centralised supplies and lower prices (Isachsen *et al*., 1992). Economic rivalry is created, as producers compete for customers, and prices for goods and services are offered as low as possible, while ensuring profit (Grigg, 2011). Prices of goods (in a free market) are the guiding signals for sellers and buyers to make and review the free choices they have in order to further their self-interest. Competition assures products of better quality and at reduced prices to consumers, encourages risk taking by businesses in furthering their economic interests, thus, benefitting the economy in general (Grigg, 2011). Furthermore, according to the law of demand, the quantity demanded increases as prices of such goods decline.

Additionally, in a free competitive market, technological innovation is stimulated and encouraged, enabling a producer to make a head start in meeting the needs of consumers in new and creative ways (Rothbard, 1993). This subsequently encourages investments, price system, and the profit/loss market incentives, and likewise, capital investment and production are guided into the proper path (Rothbard, 1993). This thesis applied the theory used to describe the free competitive market in developing a long-term development path for the sustainable growth of the small wind energy sector in the country.

6.3.2 The Path to Cost Competitiveness

The moderate-growth path targets the cost reduction of small wind energy systems in making the systems more competitive with other distributed generations and conventional sources on the basis of a LCOE. Realising cost competitiveness is projected to result in an increased deployment of small wind systems in the country. Over time, the evolution of technologies and improved manufacturing, distribution, and installation have resulted in performance improvement and cost reduction of renewable energy technologies (Ayompe, 2011). This moderate-growth path indicates that the commercial utilisation of small wind generation is currently not economically viable in South Africa, however, opportunities exist to achieve economic viability and a cost-competitive market through cost reductions. The reduction of the LCOE of renewable generation can be realised by performance improvement and capital cost reduction (US DoE, 2012; IRENA, 2012).

The cost reduction mechanisms proposed by this long-term path comprise of the learning effect and economies of scale to enable a cost-competitive market and ultimately, a long-term sustainable growth of the sector. According to Winkler *et al*. (2009), the two fundamental factors that have caused reductions in the costs of emerging technologies over time are: learning by doing; and economies of scale. The combined impact of both factors has been analysed by learning ratios, in which the reduction of cost per unit of installed capacity for every doubling of cumulative capacity is measured. Ultimately, expanded investment will bring about cost reductions of low carbon technologies through learning by doing and economies of scale (Timilsina *et al*., 2011).

In creating the cost-competitiveness of a system, the capital costs at which the LCOE of the system becomes competitive for both conventional generation and solar PV were determined as follows (Gokcek & Genc, 2009):

$$IC = \frac{(LCOE \times Annual\ \ Energy\ \ Production\ \ ) - O\&M}{Capital\ \ Recovery\ \ Factor} \quad (1)$$

Where the Capital Recovery Factor is at a given discount rate of 10% and at a turbine lifetime of 20 years, and the operation and management (O&M) is expressed as 15% of the investment cost (IC).

$$IC = \frac{(LCOE \times Annual\ \ Energy\ \ Production\ \ )}{(\frac{i(1+i)^n}{(1+i)^n - 1}) + 0.15} \quad (2)$$

The ICs of selected turbines for this study include the capital cost of the manufacturing of the turbine system and installation costs (Gokcek & Genc, 2009; De Oliveira *et al*., 2011). The installation cost is assumed to be 30% of the capital cost, thus, the capital cost of the system is $0.77IC$ (about 77% of the investment cost). Currently, the capital cost of the e300i (1 kW) and e400n (3.5 kW) systems are R30,825 and R72,012 respectively.

Competitive Cost against Conventional Generation

The average LCOE of conventional electricity to end-users is assumed to be R1.53/kWh (CoCT, 2014). The estimated capital costs of the e300i and e400n turbines at which they will become competitive with conventional generation are presented in Table 6.2, assuming that all the other factors (e.g. performance of the system) remain constant.

Table 6-2: The competitive capital cost of selected turbines against conventional source

Region	Site Location	e300i (1 kW) (ZAR)	e400n (3.5 kW) (ZAR)
Cape Peninsula	Cape Town	9,377	14,633
	Oudtshoorn	3,016	1,058
	Worcester	7,758	10,010
South Eastern	Port-Elizabeth	9,534	15,146
	Grahamstown	7,758	10,010
	Richards Bay	6,540	6,872
Central	De Aar	6,565	10,406
	Bethlehem	4,997	3,738
	Potchefstroom	3,016	1,058
Northern	Johannesburg	7,420	9,075
	Nelspruit	3,016	1,058
	Polokwane	4,044	2,224

From the comparison between the cost competitiveness of small wind generation against conventional generated electricity costs to end-users, Port Elizabeth has the most competitive costs for the two selected turbines. It has competitive costs of R9,534 and R15,146 for the e300i (1 kW) and e400n (3.5 kW) respectively, followed by Cape Town with R9,377 and R14,633. Cape Town and Port Elizabeth have the most competitive costs when compared to conventional sources in their respective regions, and De Aar demonstrated the most competitive cost in the Central region with R6,565 and R10,406, and Johannesburg, with R7,420 and R9,075 was the most competitive in the Northern region.

Competitive Cost against Solar PV Generation

According to the REIPPPP procurement document, the average LCOE for solar PV generated electricity is assumed as R0.99/kWh (Eberhard *et al*., 2014; Niekerk, 2014). The estimated capital costs of the e300i and e400n turbine systems at which they will become competitive with solar PV generation are presented in Table 5.6, assuming that all the other factors (e.g. performance of the system) remain constant.

Table 6-3: The competitive capital cost of selected turbines against solar PV generation

Region	Site Location	e300i (1 kW) (ZAR)	e400n (3.5 kW) (ZAR)
Cape Peninsula	Cape Town	6,000	9,363
	Oudtshoorn	1,930	677
	Worcester	4,964	6,405
South Eastern	Port-Elizabeth	6,100	9,691
	Grahamstown	4,964	6,405
	Richards Bay	4,185	4,397
Central	De Aar	4,200	6,658
	Bethlehem	3,197	2,392
	Potchefstroom	1,930	677
Northern	Johannesburg	4,748	5,806
	Nelspruit	1,930	677
	Polokwane	2,588	1,423

From the comparison of the cost competitiveness between small wind generation and solar PV generation, Port Elizabeth has the best competitive costs for the two selected turbine models. The location has competitive costs of R 6,100 and R 9,691 for the e300i (1 kW) and e400n (3.5 kW) respectively, followed by Cape Town with R 6,000 and R9,363. Cape Town and Port Elizabeth have the most competitive costs against Solar PV generation in their respective regions, and De Aar demonstrated the most competitive costs for small wind generation in the Central region with R 4,200 and R6,658, while Johannesburg was most competitive in the Northern region, with R4,748 and R5,806.

6.3.3 Learning Curves and Cost Reduction Potentials

Learning curve is a foremost alternative mechanism to cost reduction potential and evaluation of future costs (Gross *et al*., 2003; Beith *et al*., 2004). The learning curve is a long-term tactical model rather than a short-term model, and it is a powerful tool in the formulation of a competitive strategy (Bodde, 1976). The moderate-growth path applied the learning curve model to project the future costs of small wind systems in the country. The learning curve concept argues that the accumulation of the application or initial utilisation of a technology increases the resultant experience, which consequently results in the processes involved being optimised (Ayompe, 2011). Winkler *et al*. (2009) stated that the first sample of a production is generally more costly than subsequent models, due to the latter going through a smarter and more cost-effective production process. This concept ensures cost reductions for energy technologies (IEA & OECD, 2000). Improvements in technology specifically are generally economic in nature, and therefore lead to reduced costs, causing frequent changes in cost as a proxy for learning-by-doing (Ferioli *et al*., 2009). The learning effect is expressed as a function of the experience attained from an increase arising from the cumulative capacity or output of a product, and is measured in terms of reduction in the unit cost of the product (Jamasb & Kohler, 2007), and demonstrated by plotting a reduction in technology costs against its accumulated production (Wiesenthal *et al*., 2012).

The learning curve model for small wind energy systems can be expressed as (Nemet, 2006, Winkler *et al*., 2009; Ferioli *et al*., 2009; Nemet & Husmann, 2012):

$$C_t = C_0 \left(\frac{Q_t}{Q_0}\right)^{-b} \tag{3}$$

Where C_t (in R/kW) is the unit cost of the system at future time t, C_0 represents the initial cost at the arbitrary starting year, Q_t is the cumulative installed capacity of the system at time t, Q_0 is the cumulative installed capacity at the arbitrary starting year, and b is the learning parameter, which is the exponent defining the slope of the power function that is negative due to declining costs.

For each doubling of cumulative installed capacity, the costs reduce to a value represented by the multiplication of the initial cost of the system by a factor termed the progress ratio (Ayompe, 2011). The progress ratio (PR) is thus (Nemet, 2006, Winkler *et al*., 2009):

$$PR = 2^{-b} \tag{4}$$

Furthermore, while the PR is referred to as the reduced cost per unit, another important factor, termed the learning rate (LR), is defined as the cost saved for an increase in cumulative production (Winkler *et al*., 2009), and can be expressed as:

$$LR = 1 - PR \tag{5}$$

Regarding the design of the technology learning model, the cost reduction rate reacts to changes in the production growth, however, the learning rate of production diminishes over time as doubling of capacity occurs. The function graph of the learning rate is expressed as a straight line in a log–log space, however, the shape is logarithmic in normal space, signifying that the learning rate is declining (Winkler *et al*., 2009). A larger volume of a technology or product is logically expected if it costs less to produce per unit. . The following section projects the future costs of small wind energy systems, in the context of modelling cost reduction for the systems in order to obtain sustainable growth in the sector.

6.3.4 Projected Costs of Small Wind Energy Systems

The rate for the learning curves varies in literature. According to Gross *et al*. (2003), the learning rates of industrial products are generally between 10% and 30%. The learning rates employed in this thesis are within the same range. A learning rate of 15% was used for the moderate-growth development path in this study that is in line with the future projections for wind power (IRENA, 2012).

In extrapolating the future cost of the systems, the estimation of the future installed capacity of small wind systems is essential. Thus, growth rates of 20%, 25%, and 35% were proposed for the moderate-growth path for the periods from 2016 – 2020, 2021 – 2025, and 2026 – 2030 respectively. These growth rates are based on the inputs from industrial experts, and the growth pattern of the solar PV industry (that share some characteristics with the small wind) over the past years (Greenpeace & EPIA, 2011; Gsanger & Pitteloud, 2014), and the rates are supported by simplified and cost-effective administrative measures, marketing, and public awareness. The country's cumulative installed capacity for SWT in this path is demonstrated in Figure 6.4. The cumulative installed capacity under the moderate-growth path would be about 19 MW by 2030.

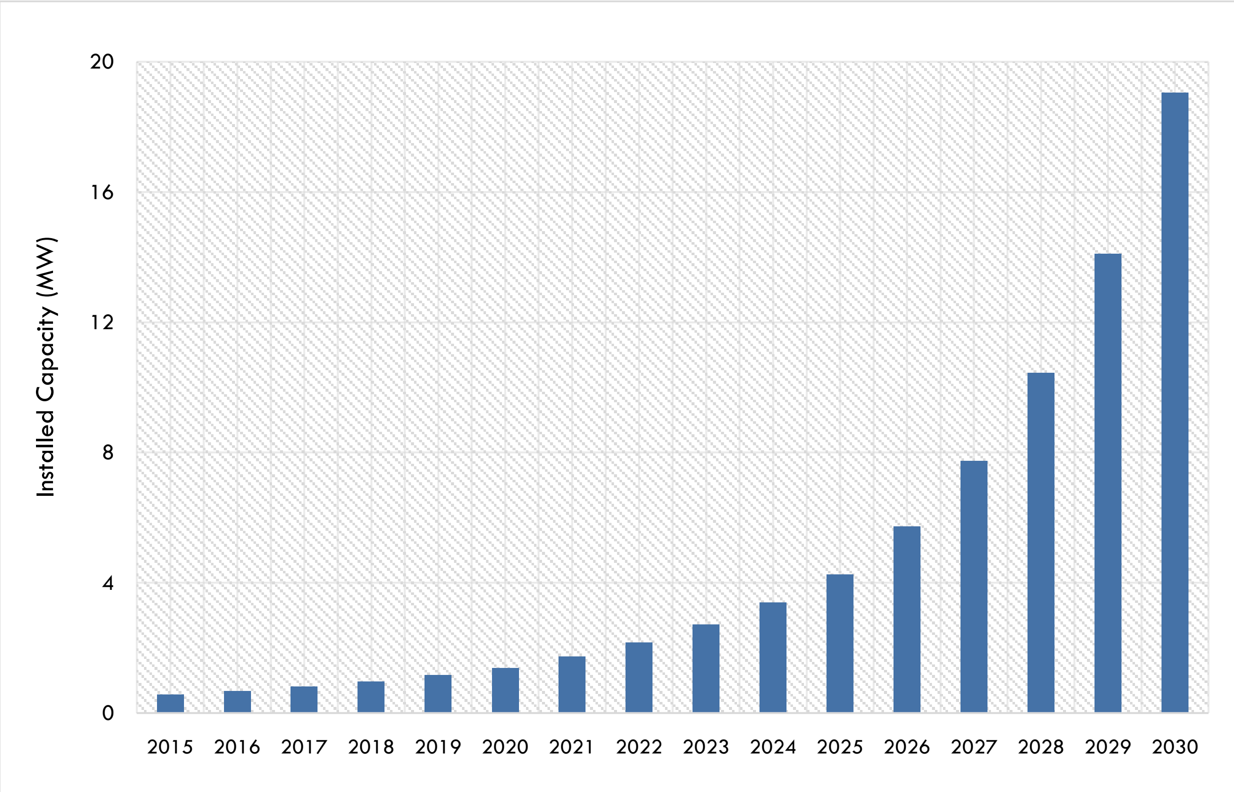

Figure 6-4: Projected cumulative installed capacity under the moderate-growth path

Using the present value of costs (ZAR_{2015}) of small wind energy systems (i.e. R 30,825 and R 72,012 for the e300i (1 kW) and e400n (3.5 kW) respectively), a yearly learning rate of 15%, the market growth rates, and equation (3), the learning curve was applied to model the outcome of the cost reduction of the two selected commercially available small wind energy turbines in the moderate-growth development path. The projection of their future costs beyond the base year 2015 is presented in Figures 6.5 and 6.6.

Similarly, the projected costs for small wind energy systems against the cumulative installed capacity are depicted in Figures 6.7 and 6.8. The cumulative installed capacity for South Africa was used to explain the cost reductions, not that of the global capacity, in accordance with other existing studies (ISET, 2005; Neij *et al*., 2003).

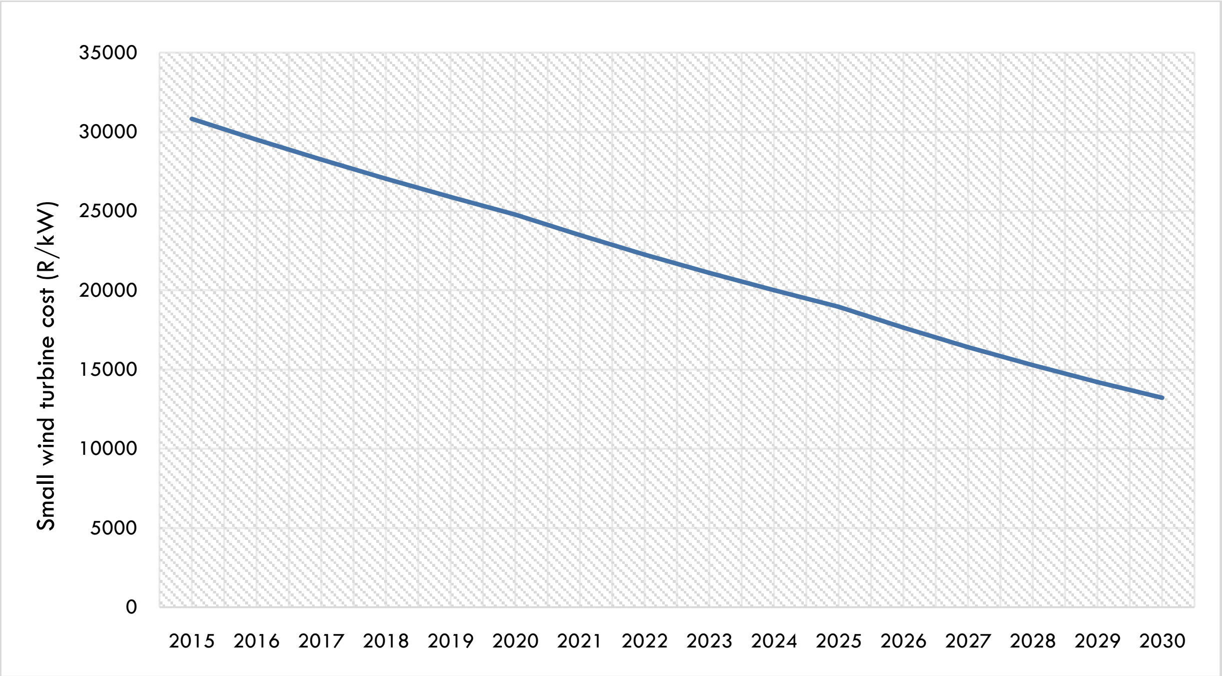

Figure 6-5: Projected costs for e300i (1 kW) beyond the present cost value of base year 2015

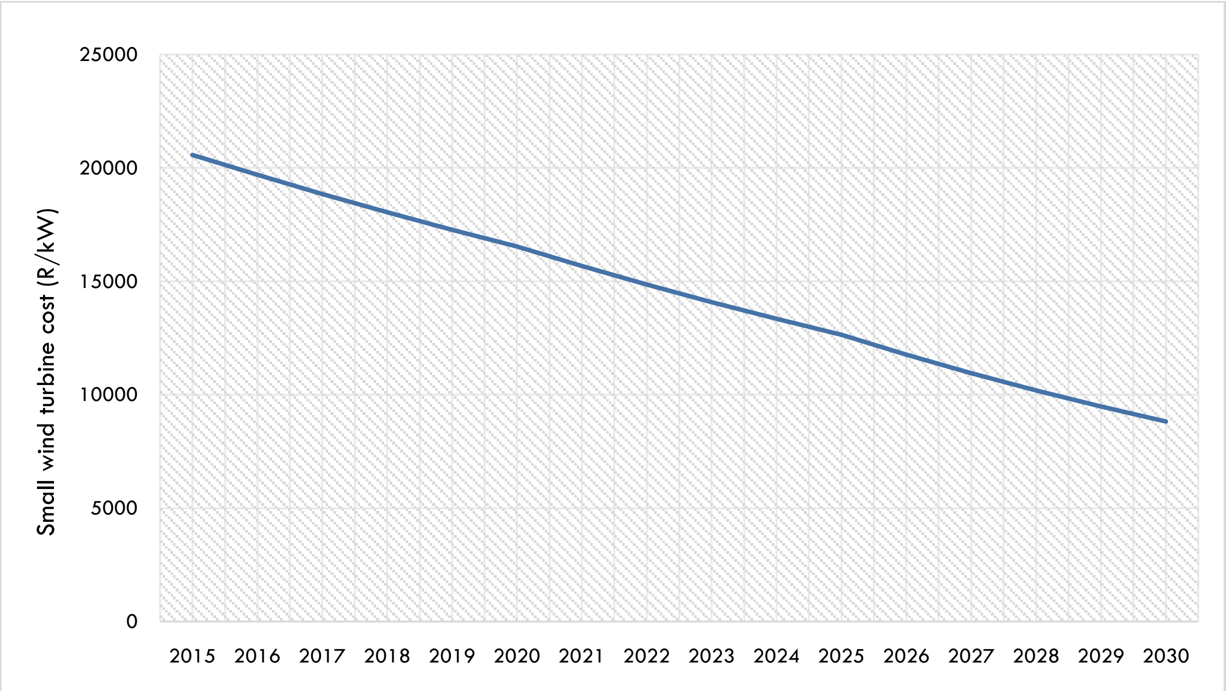

Figure 6-6: Projected costs for e400n (3.5 kW) beyond the present value of base year 2015

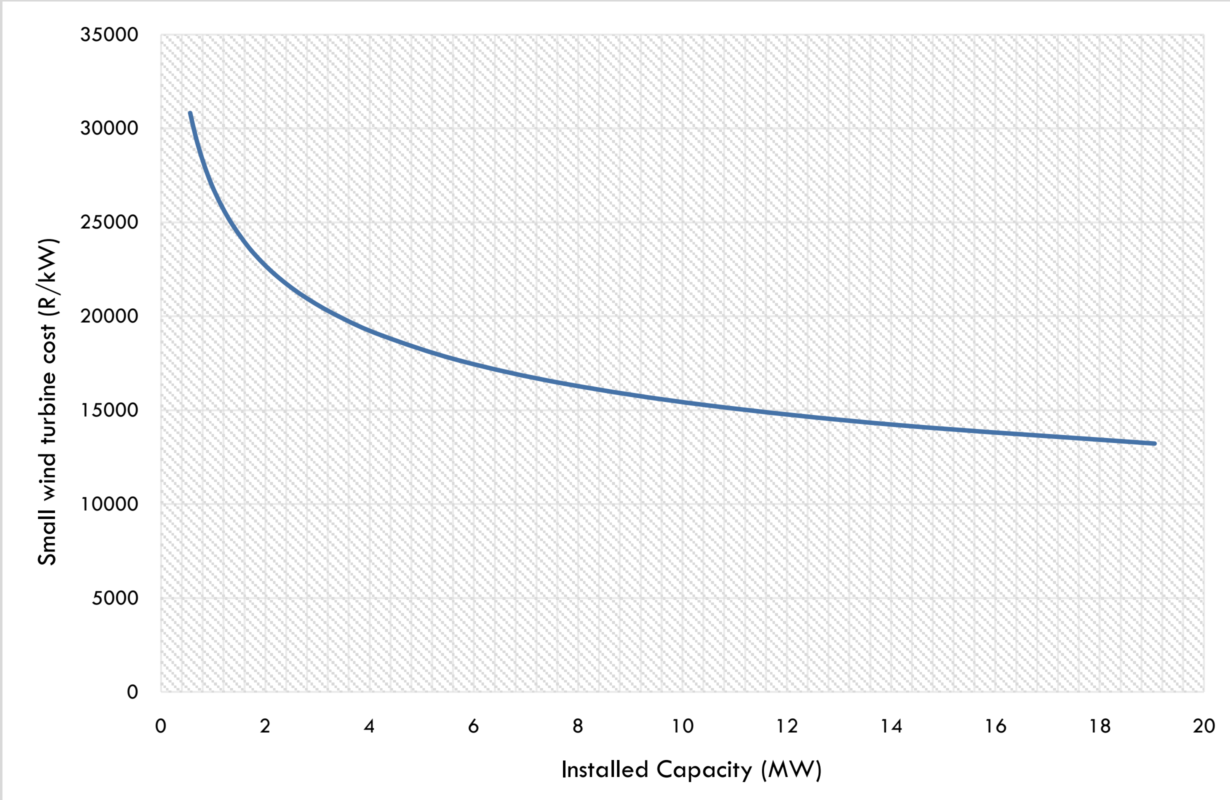

Figure 6-7: Projected costs per kW for e300i (1 kW) against cumulative installed capacity

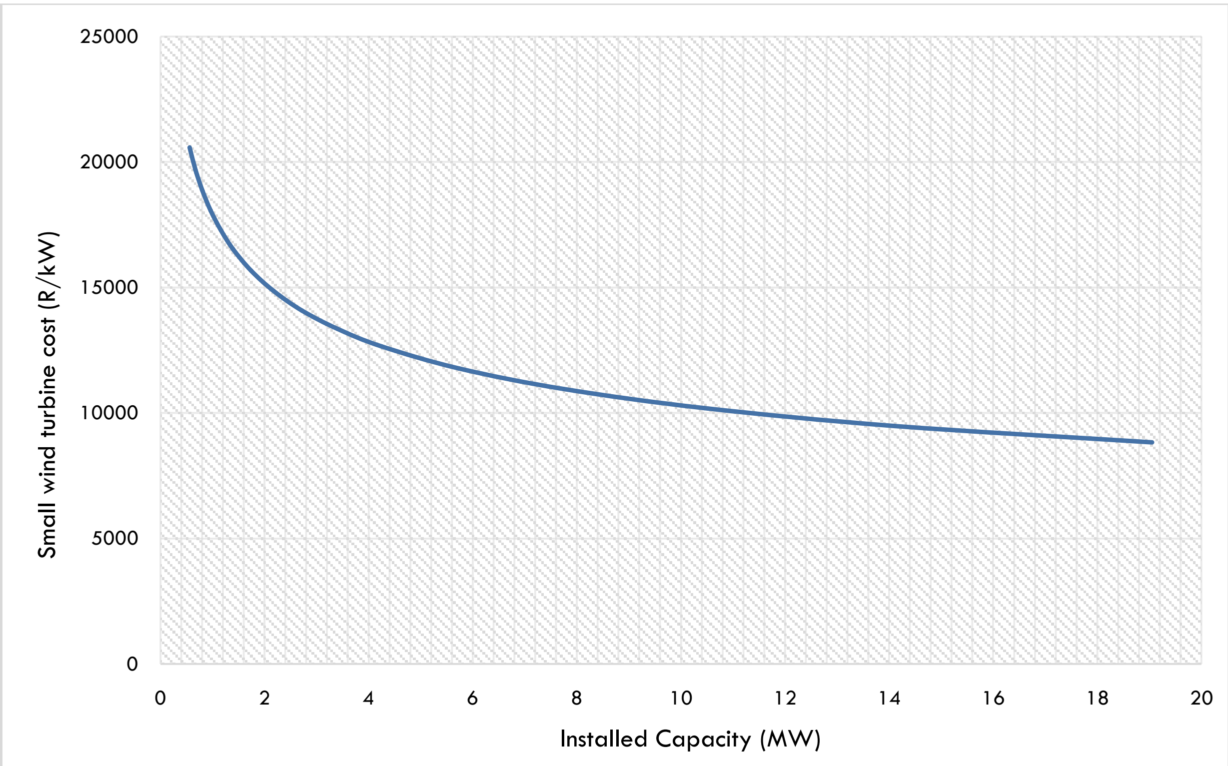

Figure 6-8: Projected costs per kW for e400n (3.5 kW) against cumulative capacity

The costs of the turbines decrease with an increase in the installation year and likewise the installed capacity of the systems increases for a given year. The extrapolation of the curves gives an estimation of the capacity at which a specific cost level would be realised. Furthermore, the respective years in which the competitive costs of the small wind systems in the different locations against conventional and solar PV generation will be realised can be determined from the curve. Between the base year 2015 and 2030, the costs of small wind energy system per kW are projected to decrease from R 30,825 to R 13,221 for the e300i (1 kW) and from R 20,575 to R 8,824 for the e400n (3.5 kW).

6.3.5 Manufacturing Scale-Up

In further pursuit of a path to a cost-competitive and sustainable market for small wind systems, this research study argues that understanding the relative significance of manufacturing scale-up and economies of scale on the production cost of small wind energy systems is essential to achieving further necessary cost reduction of the systems. Economies of scale are achieved when the average cost (cost per unit of output) of production reduces due to a higher level of productivity or as the production output increases (Pratten & Dean, 1965; Celli, 2013). Thijssen and Thijssen (2007) are of the opinion that a higher production volume can have an effect on technology cost in several ways, including: enabling higher efficiency of utilisation of production equipment; utilising a lower-cost production technique, which may be prohibitive at low volume due to high capital cost (e.g. automated assembly); and a reduction in the prices of raw materials and purchased components.

Aiming at a higher production volume in order to realise competitive market, increase quality, and ultimately cost reduction of the systems, this thesis advocates the extensive expansion of the manufacturing capabilities and opportunities for small wind turbines in the country. Therefore, for related stakeholders, investment decisions must now be centred around strategies for instituting new manufacturing capacities and securing supply chains associated with the integration of a complete wind energy scheme. Currently, firms producing small and medium wind turbines from mainly local designs and materials in the South African wind market include Kestrel Renewables, Winglette, Adventure Power, Palmtree Power, Isivunguvungu, and African Wind Power. It is desirable to allow new market entrants that can transfer manufacturing and supply chain management experience from other successful industries.

This study, in order to identify the manufacturing potential beyond the currently active wind manufacturing firms in the country, and to further realise higher productivity, studied South Africa's Standard Industrial Classification coding system (Statistics South Africa, 2012) and the South African Department of Trade and Industry's (DTI's) research report on the performance of the manufacturing sector (DTI-SEDA & Um Jwali, 2012). This was done in order to determine South Africa's manufacturing companies with the technical potential to enter the wind turbine component market. The result, as presented in Table 6.4, revealed thousands of firms currently manufacturing products (under one or more SIC codes) useful in wind turbine component production.

Table 6-4: SA manufacturers with the technical potential to operate in the turbine component market, 2008

SIC Code	Code Description	Number of Firms	Turnover (ZAR '000)	Total Employees
19, 20 & 22	Petroleum, Chemical Products, Plastics, Rubber, Coke	1800	449,429	171,114
23	Glass, Cement, Other Non-Metallic Mineral Product	–	48,551	63,289
24, 25 & 28	Metals, Metal Products, Machinery and Equipment	–	311,604	310,935
27	Electrical Machinery, Appliances and Apparatus, Motors, Generators, Transformers, Electronic Components and Assemblies	–	34,228	41,308
TOTAL			843,812	586,646

Sources: Statistics South Africa (2012), DTI-SEDA and Um Jwali (2012), and author

To further support development in manufacturing and an increase in local production capacity, a strong commitment to an appropriate, effective, comprehensible and focused policy is the first step towards maximising the local potential in the industry (Lund, 2009; Ninela, 2013). Table 6.5 presents the list of local content incentives offered by the South African Department of Trade and Industry. These production incentives are available to existing and intending manufacturing entities with an interest in the manufacturing of small wind turbines and associated components.

Table 6-5: Local content incentives for manufacturing entities in South Africa

Incentive	Objective
Industrial Policy Project (section 12I) Tax Incentive	The 12I Tax Incentive is designed to support Greenfield investments (i.e. new industrial projects that utilise only new and unused manufacturing assets), as well as Brownfield investments (i.e. expansions or upgrades of existing industrial projects). The new incentive offers support for investment in manufacturing assets, to improve the productivity of the SA manufacturing sector; for the training of personnel, for the improvement of labour productivity and the skills profile of the labour force.
Manufacturing Competitiveness Enhancement Programme (MCEP)	This incentive provides a cost-sharing cash grant of between 30% and 70% of expenditure incurred, calculated based on a percentage of the applicant's average manufacturing value-added (MVA) achieved for a specific period. The grant is capped between 10% and 25% of the manufacturing value addition. The grant can be claimed against qualifying expenditure relating to capital investment, cleaner technology and resource efficiency improvement, enterprise-level competitiveness initiatives, feasibility studies and cluster competitiveness improvement initiatives. The MCEP also supports the Capital Investment and Green Technology and Resource Improvement components.
Manufacturing Investment Programme (MIP)	The MIP is a reimbursable cash grant for local and foreign-owned manufacturers wishing to establish a new production facility or expand an existing facility. It is a tax-free grant calculated based on the project size and payable over a two year period. The objectives are to stimulate investment in manufacturing; increase employment opportunities; and sustain enterprise growth. Investors in new and expansion projects in the SA manufacturing industry are eligible.
Support Programme for Industrial Innovation (SPII)	The SPII is designed to promote technological development in South Africa's industry, through the provision of financial assistance for the development of innovative products and/or processes. The SPII specifically focusses on the development phase, which starts at the conclusion of basic research and ends at the point when a pre-production prototype has been produced. The development should represent significant advance in technology; subsequent production must take place within South Africa; and the intellectual property must reside in a South African registered company.
SEDA Technology Programme (STP)	The STP is a division of SEDA (Small Enterprise Development Agency) focusing on technology business incubation, quality, standards and technology transfer services and support to small enterprises. This program seeks to stimulate economic growth and development through facilitating technological innovation, increasing the accessibility to, and utilisation of technology and technical support for small enterprises. The STP has a Technology Transfer Unit with objectives aimed at providing funding for small enterprises to acquire the necessary technology and technical support for effective technology transfer transactions.

6.4 Projected Financial Benefits

This study projected the financial benefits that would accrue to the country from fuel savings by implementing the moderate-growth development path and actualising the projected installed capacity. This financial benefit estimation is based on a study by the CSIR Energy Centre, based on the actual diesel and coal fuel savings and avoiding the "unserved energy" from the first operational 1.8 GW of wind and solar projects (Calitz *et al*., 2005).

The CSIR analysis on wind projects from January to June 2015 demonstrated that:

- On June 30 2015 800 MW of wind capacity generated 925 GWh (0.93 TWh)
- Wind projects replaced 603 GWh from diesel-fired Open Cycle Gas Turbines (OCGTs) and 305 GWh from coal-fired plants
- 17 GWh of "unserved energy" (load shedding) was avoided

Multiplying the energy values with the financial values for diesel and coal,

- The fuel saved are worth R1 446 million (diesel) and R77 million (coal);
- The wind projects saved a total R1.5 billion from diesel and coal fuel costs; and
- This savings occurred despite the R1.2 billion in tariff payments to IPPs

Thus, the wind development projects generated up to R0.3 billion more in financial benefits than their costs.

Extrapolating the CSIR analysis to estimate the financial benefit of the small wind project under the moderate-growth development path, i.e. the cost saved from diesel and coal fuel, assuming the existing trends will continue:

- The installed capacity of small wind systems is projected to reach 19 MW by 2030 and it is estimated that they will generate 21.56 GWh of electricity.
- This generation is projected to replace 14.32 GWh of electricity from diesel-fired OCGTs and 7.24 GWh from coal-fired plants by 2030.
- The projected small wind installed capacity would save an estimated R34 million (diesel) and R2 million (coal).

Therefore, subjected to a competitive and sustainable growth path, small wind energy systems would save the power system an estimated total of R0.036 billion in diesel and coal fuel costs.

Adhering to the requirements of the moderate-growth path, the learning curve is expected to drive cost reduction and the competitiveness of the small wind sector. Investments are required to realise the learning curve, in order to make the technology cost-efficient. This ‘learning investment’ includes the cost of R&D activities conducted by the commercial market actors, who eventually will want to recoup their costs through market revenues as the technology improves. Policies mobilising resources for these investments must be developed. Overlapping of the learning investments and government expenditures for R&D may be considered. Injecting a substantial proportion of the projected fuel savings from diesel and coal into R&D and scaling up of manufacturing are proposed to make the technology competitive and provide sustainable growth in the sector. These estimated financial benefits accruable to the country from fuel savings should serve as a motivation for the government to financially support the near-term and long-term development paths for future growth of the small wind sector in South Africa.

6.5 Conclusion

This chapter proposed two growth development paths for the economic viability and future growth of the small wind sector in South Africa. The advanced-growth development path, also termed the market pull path, is a near-term solution to quickly grow the market and realise mass deployment of the technology by addressing the limitations of insufficient financial incentives and policy uncertainty. It is a temporary support measure, and primarily dependent on financial incentives for market growth, i.e. it is incentive-oriented.

For this path, the thesis proposed the investment capital subsidy as a means to tackle the high investment costs of the systems (which is largely considered as the greatest hurdle to small wind deployment), the amount of subsidy that can be made available to consumers in the different locations selected in the country (i.e. the percentage of investment costs to be given as capital subsidy), and the percentage of capital subsidies provided for different LCOEs. Furthermore, the study projected the market growth for small wind generation when supported by the advanced-growth path in terms of the cumulative installed capacity. The percentages of the investment costs for the e300i (1 kW) and e400n (3.5 kW) that can be assessed as direct capital subsidies by the consumers ranged between 10% and 30% and 1% and 21% respectively. The cumulative installed capacity for the system is projected at about 12.9 MW by 2030. The study proposed that the reduction in the amount of subsidy granted or its gradual winding down over time should be subjected to the gradual cost reduction of the technology.

The moderate-growth development path, equally termed the technology push path, is a long-term solution that is projected to result in viability and sustainable growth of the sector, thus, over time fully addressing the limitations of high investment cost and uncompetitive LCOE. It is independent of the market pull financial incentives for sustenance, but proposes self-sustainability through the establishment of technology push policies and cost-competitive incentive mechanisms that will motivate increased R&D for performance efficiency and cost reduction of the technology.

This path, in enabling the cost-competitiveness of the system, computed the capital costs at which the LCOE of the systems becomes competitive with both conventional generation and solar PV generation, and subsequently proposed the cost reduction mechanisms, which comprised of the learning effect and economies of scale, to achieve this reduced capital cost. The learning effect model was used to assess the prospect of commercial viability, and it projected the future costs of small wind energy systems through modelling cost reductions for the systems. Additionally, the learning effect model estimated the cumulative capacity at which specific reduced costs of the systems would be achieved by demonstrating the projected costs against the cumulative installed capacities. By 2030, the cumulative installed small wind capacity will be 19 MW under the moderate-growth scenario. Between the base year 2015 and 2030 the projected reduced costs for the e300i (1 kW) and e400n (3.5 kW) turbine models will decrease from R30,825 to R13,221 and R20,575 to R8,824 respectively.

Furtherance to the pursuit of cost reduction of the systems, the path proposed an increase in manufacturing activities of and opportunities for small wind turbines in order to achieve a higher production volume, thus realising the necessary cost reduction and a competitive market. To reach these conclusions, the researcher identified existing local firms that are active in the production of small and medium wind turbines designing and manufacturing mainly locally, and further determined South Africa's manufacturing companies with the technical potential to operate in the wind turbine component market. The results unveiled thousands of firms currently manufacturing products (under one or more SIC codes) useful for wind turbine component production. Additionally, in order to support domestic manufacturing and increase local production capacity, the study presented a list of manufacturing incentives offered by the South African Department of Trade and Industry that are available to existing and intending manufacturing entities with the interest in the production of small wind turbines and associated components.

Finally, the financial benefits that would accrue to South Africa from fuel savings (from diesel and coal) by executing the moderate-growth path and achieving the projected installed capacity was projected by the thesis. The study estimated a total saving of R0.036 billion in diesel and coal fuel costs by small wind projects, and these savings are expected to result in a competitive and sustainable growth of the sector.

CHAPTER 7

VALIDATION OF THE SMALL WIND DEVELOPMENT PATH

7.1 Introduction

The previous chapters have analysed the research problems and proposed two development paths to resolve the research problems. The effects of the available policies benefitting small wind energy systems and the technology performance of the systems on the viability and sustainable growth of the sector in the country were analysed by this study. The thesis tested and established that the viability and sustainable growth of the sector is limited by two independent variables, and further identified and revealed the specific limitations. Consequently, in order to overcome these limitations and resolve the research problems, the research study proposed a development path to a competitive and commercially viable market, and the sustainable growth of the system.

In this chapter, the study continued beyond just analysing and resolving the research problems but to prove that the proposed solution (development path) to the problem actually solved the problem or is a valid solution. This process measured the success of this thesis against these research problems. The following steps were followed towards realising the validation of the small wind development path:

- The assumptions made in each of the solutions proposed by the small wind development paths were validated.
- Afterwards, industrial professionals validated the results obtained from the analysis of these assumptions, by establishing that they are achievable, and by determining that small wind energy systems can practically contribute to the energy portfolio of South Africa.
- Thus, the validation of the development paths is demonstrated by induction, i.e. both the assumptions and the results obtained were realistic and credible, thus, the development paths proposed for small wind energy systems by this study are valid and trustworthy solutions. However, the fool-proof validation of the development paths will only be realised following implementation, and this goes beyond this thesis.

7.2 Validation of the Advanced-Growth Development Path

The advanced-growth development path assumed the proposition of the investment capital subsidy as a near-term temporary market-pull policy solution for the viability and future market development of the small wind sector in the country.

Validating Investment Subsidy as a Market-Pull Development Policy

The provision of an investment capital subsidy is the solution proposed to temporarily reduce the high investment cost burden on consumers of small wind turbines (by granting them financial incentives - capital cost grant or loan), and it also provides a market pull mechanism for an increase in demand and the quick growth of the sector in South Africa. This financial incentive program has been tested and was successful in many off-grid markets as a first stimulus to initiate a ‘virtuous cycle’ of increased demand, investments in new production facilities and cost reduction by economies of scale, creating further development and deployment (Kimura & Suzuki, 2006). The successful implementation and outcomes of the PV Systems Subsidy Program (Japan) and the Low Carbon Buildings Programme (United Kingdom) validated the assumption by this thesis that an investment capital subsidy will be a market pull development mechanism for small wind systems in South Africa.

The Japanese capital subsidy program was among the market-creation policies established for PV systems by the Ministry of International Trade and Industry (MITI) and the electric power companies in the early 1990s against the high up-front cost of these systems, their longer pay-back periods, the low market deployment and growth, and the consequent growing criticism against these circumstances (Fujino, 2004; Kimura & Suzuki, 2006). The incentive program is widely recognized as a critical institutional arrangement that supported the PV market expansion the mid 1990s (PVTEC, 1998), making Japanese PV development one of the successful cases of energy technology innovation (IEA, 2003; Bolinger *et al.*, 2002). Following the announcement of appropriation for the 700 Roofs Program late in 1993 by the MITI, producers of PV systems quickly organized mass-production lines for the manufacturing of residential PV systems, and there suddenly emerged a large market for PV power application, expectedly as much as 2 MW, signifying a 40% growth of the PV power application market (Kimura & Suzuki, 2006). The subsidy program attracted much more consumers than expected, with over 1 000 and 5 000 applicants requesting for the subsidy in the first and second year of the 700 Roofs Program respectively (Kimura & Suzuki, 2006). Participants in the program rapidly increased since the start of the program, with more than 60 000 annual installations in the year 2004 (Kimura & Suzuki, 2006). The rapid increase of applicants clearly showed that the program greatly inspired consumers' motivation for purchasing PV power, and therefore the program succeeded in creating a niche-market. The subsidy program was terminated in 2005 due to the target cost of these solar PV systems being achieved in 2002, and the PV market had grown to a position of self-sustainability without subsidies (MOF, 2003; Kimura & Suzuki, 2006).

Another successful initiative validating investment subsidy as a demand-pull mechanism is the Low Carbon Buildings Programme (LCBP), initiated by the UK government in January 2006 with the core aim of supporting the growth of the UK microgeneration industry. The LCBP was a key measure used to overcome the constraints of high upfront costs and to foster the further distribution of microgeneration by providing grants to householders, community groups and commercial organisations (LCBP-1); and non-profit and non-domestic projects (LCBP-2) (Ipsos MORI, 2011). An internal comprehensive review of the LCBP by the Department of Energy and Climate Change and an external independent evaluation by Ipsos MORI and CAG Consultants, adjudged the LCBP grant schemes to have provided significant stimuli for the growth of the microgeneration industry (Ipsos MORI, 2011). It provided 18 240 grants for the capital and installation costs of microgeneration, supporting a significant proportion (around 20%) of all microgeneration installations in the UK, more than any other scheme (EST, 2007). Most stakeholders agreed that the program has contributed significantly to the promotion of small-scale renewables. A report for EST (2007) estimated that there is about 100 000 microgeneration installations across the UK. An earlier study by the Environmental Change Institute (2009), however, had estimated that there was a technical potential for around 53.6 million microgeneration installations by 2050 (about 1.7 installations per dwelling) across the UK. During the LCBP operation period, a rapid increase in the utilisation of microgeneration technologies, with significant growth of the Clear Skies Program (preceding the LCBP) between 2002 and 2006 that was sustained between 2006 and 2009 under the LCBP (Ipsos MORI, 2011).

7.3 Validation of the Moderate-Growth Development Path

The moderate-growth development path proposed the learning and scale effects as long-term solutions to achieve self-sustainability or for the long-term sustainable development of the small wind sector, and the transition to a market-oriented sector without or with little government intervention.

Validating Learning Effect as a Sustainable Growth Mechanism

The learning effect is the assumption that is made, with the introduction of technology push policies and cost-competitive incentive mechanisms, to realise a cost reduction of the small wind system, to obtain cost-competitive market prices, and to foster sustainable growth of the sector. This mechanism is a certified foremost long-term alternative to the cost reduction of energy technologies and the formulation of a competitive strategy (Bodde, 1976; IEA & OECD, 2000; Gross *et al*., 2003; Beith *et al*., 2004; Ferioli *et al*., 2009). The successful outcomes from the implementation of the PV R&D Sunshine Program (Japan) and the US distributed wind energy supply chain (US) validated the assumption made by this thesis that the learning and scale effects provide cost reduction and cost-competitive tools for small wind energy systems in South Africa to achieve sustainable growth in the sector.

One important result flowing from the expansion of the Japanese PV Sunshine Program was the abundant, stable budget for PV development and learning effect (Kimura & Suzuki, 2006), as this provided a desirable R&D environment for researchers in the national laboratories, with the result that Japan has top level PV technology (Horigome, 2003). Major appliance producers, including Sharp, Matsushita, Hitachi, Toshiba, and NEC (Nippon Electronics Company), and later Kyocera, Sanyo and others joined Sunshine Program due to their excellent development of PV generation. While most of these firms had conducted in-house R&D of PV generation during the 1960s, the establishment of the Sunshine Program was the biggest stimulus for these firms to expand their activities of PV development (Kimura & Suzuki, 2006). The program not only promoted basic R&D, but also showcased a number of demonstration projects, including distributed small applications as well as a large scale solar generation plant (1 MW plant in Saijo City), and these demonstrations created an indispensable demand for solar cells (Suzuki, 2004). While the major objective of the demonstrations was system development, the New Energy Development Organisation (NEDO) demonstrations provided PV producers with the opportunity to accumulate production experience and improve process technologies through learning-by-doing (PVTEC, 1998; Suzuki, 2004). NEDO set annual targets of cost reduction, and put pressure on producers, indicating that NEDO would not buy solar cells unless the price target was achieved. Since NEDO was the sole purchaser of solar cells, the cost reduction target by NEDO was a strong incentive for firms to reduce the production cost (Takeda, 2004). Thus, the NEDO demonstration projects had a strong buy-down effect. The result of these actions and demonstrations was the steady improvement of the conversion efficiency and affordability of PV power in the 1980s. When the program was started, the efficiency (ratio of energy converted from sunlight) of solar cells produced in factories was only 5%, although champion data had 17% efficiency in the laboratory (Kimura & Suzuki, 2006). However, it is said that providing a stable production of high-quality solar cells in factories is much more difficult than in laboratories and the researchers in the factories need substantial experience and know-how in process technologies (PVTEC, 1998). The running of the program for 10 years resulted in continuous improvement of solar cell efficiency and large cost reductions (Kimura & Suzuki, 2006).

Similarly, the learning and economies of scale manufacturing techniques were keys to higher production volumes and lower costs of the distributed wind technology in the US (AWEA, 2010). Policy measures introduced by the government have provided the producers with access to learning opportunities and stimulated learning investments for the improvement of wind technologies (IEA & OECD, 2000). The observed learning rate in the US that resulted in cost reduction was due to a combination of technological and market structural changes. Public research, development and deployment (RD&D) projects for wind power have generated important insights into the technology, and the reductions in investment costs have come through large-scale deployment (IEA & OECD, 2000). Learning occurred during several stages of the implementation process. In 2008, the US Department of Energy held workshops to develop a research and development action plan for the wind energy industry, including the small wind turbine sector. Stakeholders identified more manufacturing needs and requested improvement from researchers performing research and development, with the central focus on lowering a turbine's cost of energy production, which led to a higher deployment of the technology (AWEA, 2010). Furthermore, the 2012 US market report on wind technologies on manufacturing scale-up in relation to cost reduction and more deployment, showed that the US distributed wind energy supply chain contains more than three dozen facilities (Orrell *et al*., 2013): at least 21 of them have active assemblies that distribute wind turbines and several others produce related components. These facilities are spread across 17 states.

7.4 Validation of the Results of the Development Path

This thesis assumed that the investment capital subsidy is a near-term temporary measure to realise the reduction of the high investment cost burden, increase in demand, and quick growth of the sector. Accordingly, it analysed and designed a new template for granting investment capital subsidies to consumers, and these subsidies included the provision of an allowed investment cost percentage to consumers in different locations of the country and the provision of capital subsidy percentages against different LCOEs. Additionally, the cumulative installed capacities of small wind generation, with regard to the market-pull mechanism in the development plan, were projected. Furthermore, for the moderate-growth development path, the study assumed the learning and economies of scale effect mechanisms to enable the transition in the small wind sector from an incentive-dependent market to a technology push, competitive and sustainable market. Hence, it analysed and projected the capital costs at which the LCOEs of the systems in the different locations are competitive when compared to conventional generation and solar PV systems, and it also computed the reduced costs of the systems in future.

The validation of the results of the investment capital subsidy and learning effect analyses performed for South Africa involved the participation of industrial professionals. According to Schwerin (2010), the validity of a study can be increased by the evaluation and approval of the research results by interviewees, colleagues and experts. Through a semi-structured questionnaire/interview, the professionals were offered the opportunity to provide feedback and make comments on the investment subsidy and learning effect analyses, results and recommendations, to further increase the credibility and validity of the study. Their observations and opinions were very important and completely independent without any relation to the research work, but instead to profound knowledge and experience in the wind and renewable energy sector. The wind energy-related professionals involved in the validation of the results and the entire research include:

Tumi Mailula, Deputy Director, Department of Science and Technology

Tom Pederson, Director (Wind Power), Siemens South Africa

Reinhard Marx, Managing Director, 1Energy Limited

Andre Otto, WASA Project Manager, South African National Energy Dev Institute

Leon Gouws, Director (Sales and Marketing), Kestrel Renewable

Dr. Carola Hantelmann-Nawa, South African-German Energy Programme/Development Advisor on Renewable Energy to the Eastern Cape Government

Piet Badenhorst, Senior Project Development Manager, Industrial Dev. Corporation

Ernie Aylward, CEO/Project Manager, Stellenbosch Wind Energy Technology;

Sean Poole, NMMU/South Africa Wind Energy Association

Thuthukile Mosia, Investment Case Specialist (Energy), Technology Innovation Agency

Marc Wright, Senior Associate/Technical Manager, Bio-Therm Energy (Pty) Limited.

7.5 Conclusion

The proposed solutions (two development paths) were confirmed as valid solutions to the research problems. In general, the feedback and opinions of the professionals from the industry on the development paths proposed and the entire study can be termed as representative, as they were similar and aligned. They commended the general research work and validated both the advanced-growth and moderate-growth development path results. They confirmed that the results to a large extent, though ambitious, are practical and achievable, considering that all the recommendations are supported. The documentation of their comments is presented in Appendix G. In conclusion, the validation of the development paths has been confirmed by induction, i.e. both the assumptions and the results obtained were feasible and credible, thus, the small wind development paths for the country are valid and trustworthy solutions. However, the fool-proof validation of the solution can only be achieved following the implementation of the development paths, and this exceeds this thesis.

It is imperative that the industry must have a huge responsibility in devising the research problem and the topics addressed. Thus, it can be assumed that the study is appropriate for the industry, and thereby buttressing the validity. The research objectives studied are related to each other, and formed a single entity. The empirical data was collected for different regions of the country, implying that the results can be generalised to the whole country to a large extent. However the direct validity of the results is limited to the small wind sector researched, the findings in this thesis could also be made applicable to other small-scale generations in the country.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

8.1 Introduction

The generation of electricity primarily through coal is contributing significantly to South Africa's high carbon emissions, making the country one of the highest emitters of greenhouse gases (Ayodele *et al*., 2012a). However, the country is redefining its energy combination by cultivating renewable resources, and in particular, wind energy that is a clean and environmentally friendly source of energy (Leung *et al*., 2012). According to a study by Edkins *et al*. (2010), the country has a wind power generation potential estimated at 80.54 TWh that is realisable with an installed capacity of about 30.6 GW.

In demonstration of the government's commitment to wind energy development in the country, the most recent IRP 2010-2030 proposes 8.4 GW of newly build installed wind capacity by 2030, with large scale wind turbines expected to supply a significant percentage of this capacity. However, the IRP document also requires contributions and further research in off-grid technologies and activities. The country's off-grid small wind technology sector is still in infancy (Szewczuk, 2012), thus, there is a need for further research and development if this technology is to contribute to the proposed installed capacity. This requirement for further research and development led to the purpose of this thesis, which is to formulate a development path for further growth of the small wind sector. In doing this, the thesis addressed these key questions for South Africa: *how has the available policies benefitting small wind energy systems (SWES) in South Africa affected the growth of the sector; how has the technology performance of these systems affected the growth of the sector; and how can these two factors be better developed to achieve further growth of the small wind sector in the country?*

This thesis examined policy and technology performance in order to achieve mass uptake of small wind energy systems in South Africa. According to Schwerin (2010), inconsistent policies, poor technology, a lack of planning and maintenance are key factors often responsible for the underdevelopment of renewable energy projects. This chapter provides conclusions on the entire research analyses and results, makes recommendations, and presents opportunities for further research. Most importantly, this research study contributed to the body of knowledge on small wind energy generation, as outlined in the introductory chapter, and was supported and endorsed by stakeholders from the industry.

8.2 Conclusions

This section collates the findings of the research work and measures them against the initial objectives.

Objective 1: Evaluate the effect of the available policies benefitting small wind energy systems in South Africa on the viability and future growth of the sector, and the influence of policy factors (return and risk) on the level of deployment and development.

The evaluation of the available policies benefitting small wind generations in South Africa confirmed that, the viability and growth of the sector in the country is presently limited by these policies. The results for the U.S and UK markets alongside SA showed the synergy between the return and risk factors. The return and risk factors analysed for the small wind market in South Africa were not favourable, which expectedly resulted in low levels of deployment and development. It can further be concluded from the US and UK case studies that, while the availability of several incentives is an important condition for the development of the sector, an effective increase in deployment will only occur if the policy risks are properly managed. This research study has demonstrated that, the different levels of development and deployment are largely influenced by the return-risk factors.

The study of the available South African policies for the small wind sector revealed limitations which include insufficient financial incentives, policy uncertainty, poor administrative processes, and absence of a long-term policy plan for a free sustainable market development. The provision of more financial support programs has the prospect of advancing the development and deployment of the small wind systems in the country, however, a continued and sustained growth for the market is more desirable, and this requires an alternative development path to ensure that the market becomes cost-competitive and self-sustainable.

Objective 2: Evaluate the techno-economic performance (energy productivity and economic viability) of the small wind energy systems in different locations in South Africa, and their impact on the viability and future growth of the sector.

The evaluation of the technology performance of the systems confirmed that the viability and further growth of the small wind sector in South Africa is limited by the generated energy and economic performances of these systems. The small wind systems are yet to be economically viable in SA when considering the current policies and assumptions for the sector. The Port Elizabeth and Cape Town-related regions, however, are comparatively more productive than other regions of the country.

As revealed by this thesis, the high investment costs, uncompetitive LCOE, and the absence of a long-term technology development plan/path to sustainable growth for the small wind systems, are current limitations to the viability and future growth of the sector in SA. Continued and sustained growth is essential to ensure that the sector gets to the phase in which more performance efficiency, future cost reduction, self-sustainability and sustainable growth are attained, and these require an alternative development path.

Objective 3: Propose an alternative near-term development path to temporarily address the limitations identified, stimulate an increase in demand, and quickly grow the small wind sector in the country.

The study proposed an advanced-growth development path, a temporary near-term solution that will act as a stimulus to increase demand and quickly grow the market. The path is primarily dependent on the provision of market pull financial incentives to drive the demand for and the mass deployment of the systems. The development path proposes investment capital subsidy through the granting of a calculated percentage of the investment costs to assist consumers in installing the small wind systems. This investment subsidy, in the form of capital cost grants or loans, will expectedly address the limitation posed by high up-front costs. The study proposed a reduction in the subsidy amount with a gradual reduction in the costs of the technology.

<u>Objective 4</u>: Further propose a long-term development path, leading to cost-competitiveness of the systems, commercial viability and sustainable growth of the sector.

The study further proposed a long-term solution, the moderate-growth development path, to bring about cost reductions of the systems, competitiveness, and sustainable growth of the sector. This sustainable path does not rely on providing consumers with market pull financial incentives for sustenance, but supports self-sustainability through the establishment of technology-push policies and cost-competitive incentive mechanisms that will bring about increased R&D, learning and scale effects. As established by the study, increased R&D, learning effect and scaling up the manufacturing will expectedly result in a cost reduction of the technology, a free and competitive market, commercial viability, and sustainable subsequently growth in the small wind sector. Furthermore, the thesis suggested an injection of a substantial proportion of the estimated fuel savings from diesel and coal in the ‘learning investment’ (cost of R&D activities, learning and scale effect, etc.). These fuel savings need to be a motivation for the government to financially support the near-term and long-term paths for the future development of the sector in the country.

8.3 Recommendations

The various analyses carried out on the policies, performance, and case studies in this thesis demonstrated that governmental support for small wind turbines and renewable energy in general is of central importance. Thus, from these findings the following is recommended:

- *Market formation policies*: The development path and validation case studies demonstrated that the combination of both the market pull and technology push policies is vital for the development of emerging technology. Market pull policies (i.e. capital subsidies) should be considered and implemented, as not only technology-push can sustain private investments for a long period. Several years do go by for an emerging technology to be fully competitive, even where there is improvement in the performance and economic viability of the technology (Kimura & Suzuki, 2006). Furthermore, technology-push policies should be rolled out to stimulate more R&D in the field and the manufacturing of small wind turbines and related components.

- *Stable environment for research communities*: The government needs to ensure consistent and sufficient budgets for R&D activities on small wind technology, since it is very important for the steady development of the sector in the long term. The stable funding for PV generation in Japan was a major boost for innovation, this is in contrast with the large fluctuations of other countries' governmental budgets, which constitute a limitation (Margolis, 2002; Christiansen, 2002).
- *Long-term commitment*: The government needs to be strictly committed to support policies and must provide a long-term framework so as to nurture expectations for the future market of the small wind system, particularly for private investments, as such expectations induce them, which may even be more significant than the governmental investment. The PV Sunshine Program in Japan showcased a very determined commitment, stimulating private investment much more than the governmental investments (Kimura & Suzuki, 2006).
- *Stable and flexible source of budget*: In order to eliminate budgetary fluctuations for the market pull and technology push policies, the government must put a stable and flexible source of budget in place, because this is effective and useful. For the Japanese PV Sunshine Program, the main financial source for growth experienced by the program was the revenues from the Electricity Tax (*Special Account*) (Kimura & Suzuki, 2006), and this greatly contributed to the program surviving far longer than ten years.
- *Streamlining of administrative processes and capacity building:* Policymakers need to introduce simplified and clear-cut guidelines, rules, regulations and responsibilities, and streamline access to financial incentives, permitting, and other administrative processes for installers and consumers in the country. Capacity building for related departments of government and municipal authorities and provision of current information and regulations are equally essential. Similarly, the policy design should seriously consider negative criteria like corruption and low remunerations in order to avoid limitations to mass deployment.

- *Residential and awareness demonstration projects:* The installation of small wind turbines in selected neighbourhoods in townships and cities to educate people on their operation and benefits to create more public awareness for residential wind options, is recommended. This will possibly lessen the general fear and doubt people have for unfamiliar technology. This proposed initiative can be an opportunity to assist governments to boost public interest and involvement in voluntary green energy initiatives and to locally advertise governments' contribution to renewable energy development.
- *Demonstration projects for academic learning and green promotion:* Small wind initiatives in academic institutions and public facilities for the purpose of education and to demonstrate the performance and practicability of small wind projects should be promoted. Case studies of small wind projects installed in the Mandela School of Science and Technology in the Eastern Cape by Siemens South Africa and Laq qui Parle Valley High School, Minnesota, US (Forsyth & Baring-Gould, 2007) should be encouraged in SA.

8.4 Further Research

This research study has the potential to be extended, and further important research originating from this study that could be required includes:

- The carbon benefit and external costs were not analysed for the environmental value of the selected turbines in this study. A further analysis of the external costs and the amount of CO_2 and other GHGs (SO_2 and NO_X) that will be avoided when small wind is utilised, is required. These analyses are essential as they can assist policy-makers to base their decisions on appropriate measures and policies.
- Further research is recommended in the learning investment for the technology. The amount that should be provided for the learning investment, guidelines, and other related issues towards R&D and the cost efficiency of the technology should be investigated. Additionally, the drivers of the cost of capital in small wind projects and the impact of policy-making on the cost of capital should be examined.

- A detailed quantitative and qualitative examination of the factors that influence the learning curve and learning rate is also required. Likewise, the relationship between the national and global learning curves and the effects from learning from other technological fields should be further studied.
- Cumbersome administrative processes contribute to unplanned extended costs, market uncertainty, and a low utilisation of the technology (Frost & Sullivan et al, 2013), thus, further research is needed to determine the value of these impacts in terms of cost, stability, technology deployment, etc., and furthermore a framework for streamlining the administrative processes relating to small wind projects must be developed.
- As further growth occurs in the installation of small wind turbines, the risks associated with the projects also increases. Risks have the capacity to reduce the industry’s desire to invest in wind energy. As a consequence, risk management is required. Further research on the identification, evaluation, and the management of these risks in small wind projects is essential.

REFERENCES

Ackermann, T. & Soder, L. 2000. Wind Energy Technology and Current Status: A Review. Renewable and Sustainable Energy Reviews, 4:315-374

Agama Energy Limited. 2003 Employment potential of renewable energy in South Africa. Paper presented at the Sustainable Energy and Climate Change Partnership, Johannesburg. Date of access: December 12, 2014

Ahmed, N.A. 2013. A novel small scale efficient wind turbine for power generation. Renewable Energy, 57:79-85.

Alcamo, J., Van Vuuren, D., Ringler, C., Alder, J., Bennett, E., Lodge, D., Masui, T. et al. 2005. Methodology for Developing the MA Scenarios. (In Scenarios Working Group, Scenarios Assessment. Washington:Island Press, 2) Date of access: October 17, 2013

Allen, S.R., Hammond, G.P., & McManus, M. 2008. Prospects for and barriers to domestic micro-generation: A United Kingdom perspective. Applied Energy, 85:528-544.

Altman, M., Harris, H., Van der Linde, A., Fleming, D., Davies, R., & Van Seventer, D. 2010. Electricity pricing and supply with special attention to the impact on employment and income distribution. Human Sciences Research Council, Swiss Agency for Development and Cooperation, Centre for Poverty, Employment and Growth.

American Wind Energy Association. 2002. Roadmap: A 20-year industry plan for small wind turbine technology. AWEA Small Wind Turbine Committee.http://www.nrel.gov/docs/gen/fy02/31958.pdf Date of access: July 2, 2014.

American Wind Energy Association. 2007. Wind Energy Basics. Washington, DC: AWEA. http://www.awea.org/newsroom/pdf/Wind_Energy_Basics.pdf Date of access: Feb. 14, 2014.

American Wind Energy Association. 2009. Small Wind Turbine Performance and Safety Standard, Version 9.1. http://www.awea.org/learnabout/ smallwind/upload/AWEA_Small_Turbine_Standard_Adopted_Dec09.pdf; 2009
Date of access: August 9, 2013.

American Wind Energy Association. 2010. Small Wind Turbine Global Market Study. Washington DC, USA.

American Wind Energy Association. 2011. The 2010 US Small Wind Market Report. Washington DC, USA.

Amusa, H., Amusa, K. & Mabugu, R. 2009. Aggregate demand for electricity in South Africa: an analysis using the bounds testing approach to co-integration. Energy Policy 37:4167–4175.

Anadon, L.D. & Holdren, J.P. 2009. Policy for Energy Technology Innovation. (In Gallagher, K.S., ed. Acting in Time on Energy Policy. Washington, DC: Brookings Institution Press. p. 89-127).

Ani, S.O., Polinder, H. & Ferreira, J.A. 2013. Comparison of Energy Yield of Small Wind Turbines in Low Wind Speed Areas. IEEE Transactions on Sustainable Energy, 4 (1);42-49

Arrow, K. 1962. The Economic Implications of Learning by Doing. Review of Economic Studies, 29155-173.

Arthur, B.W. 1988. Competing Technologies: An Overview. (In Dosi, G., Freeman, C., Nelson, R., Silverberg, G., & Soete, L., eds. Technical Change and Economic Theory. London: Pinter Publishersp. 590–607).

Asamoah, J. 2003. Greening Electricity Generation in South Africa through Wind Energy. Paper presented at the 6th International Conference on Greenhouse Gas Control Technologies 1 – 4 October 2002, Kyoto, Japan. EnerWise Africa, vol. II (pp. 1349-1352). Pretoria, South Africa

Asmus, P. 2003. Small Wind Turbine: Can they live to their potentials in the U.S.? Re-focus, 4(4):40-43, Elsevier

Audierne, E., Elizondo, J., Bergami, L., Ibarra, H. & Probst O. 2010. Analysis of the Furling Behavior of Small Wind Turbines. Applied Energy, 87:2278-92.

Aylward, E. 2015. Personal Communication with Ernie Aylward, Stellenbosch Wind Energy Technology, South Africa.

Ayodele, T.R., Jimoh, A.A., Munda, J.T. & Agee, J.T. 2012a. Wind distribution and capacity factor estimation for wind turbines in the coastal region of South Africa. Energy Conversion and Management, 64:614-625.

Ayodele, T.R., Jimoh, A.A., Munda, J.T. & Agee, J.T. 2012b. Statistical analysis of wind speed and wind power potential of Port Elizabeth using Weibull Parameters. Journal of Energy in Southern Africa, 23; 2

Ayompe, L. 2011. Performance and policy evaluation of solar energy technologies for domestic application in Ireland. (Unpublished doctoral thesis). Dublin Institute of Technology, Dublin.

Backhouse, R. 2005. The rise of Free Market Economics: Economists and the role of the State since 1970. History of Political Economy, 37(5):355-392

Badenhorst, P. 2015. Personal Communication with Piet Badenhorst, Industrial Development Corporation, South Africa.

Balduzzi, F., Bianchini, A., Carnevale, E.A., Ferrari, L. & Magnani, S. 2011. Feasibility analysis of a Darrieus vertical-axis wind turbine installation in the rooftop of a building. Applied Energy. Retrieved from http://dx.doi.org/10.1016/j.apenergy.2011.12.008.

Beck, F., Martinot, E. & Cutler, J.C. 2004. Renewable energy policies and barriers. In Encyclopedia of Energy (pp. 365-383). New-York: Elsevier.

Beith, R., Burdon, I.P. & Knowles, M. 2004. Micro energy systems: Review of technology, issues of scale and integration. London: Professional Engineering Publishing.

Bekker, B., Gaunt, C.T., Eberhard, A. & Marquard, A. 2008. Uncertainties within South Africa's goal of universal access to electricity by 2012. Journal of Energy in Southern Africa, 19(2):4-13

Bellu, L.G. 2011. Development and development paradigms: A (reasoned) review of prevailing visions. EASYPol Module 107. Food and Agriculture of the United Nations.

Bergek, A. & Jacobsson, S. 2006. A framework for guiding policy-makers intervening in emerging innovation systems in 'catching-up' countries. European Journal of Development Research, 18(4):687-707 Dec 2006.

Bergey, M. 2001. The sleeping giant: The role of small wind in America's energy future. In Proceedings of Wind Power. Washington, D.C.: American Wind Energy Association.

Bergman, N. & Jardine, C. 2009. Power from the people: Domestic micro-generation and the Low Carbon Buildings Programme. Environmental Change Institute.

Bhattacharya, P. & Bhattacharjee, R. 2010. A study on Weibull distribution for estimating the parameters. Journal of Applied Quantitativve Method, 5:234–241

Bird, L., Bolinger, M., et al. 2005. Policies and market factors driving wind power development in the United States. Energy Policies, 33(11):1397-1407.

BirdLife. 2002. Wind farms and birds: An analysis of the effects of wind farms on birds, and guidance on environmental assessment criteria and site selection issues. http://www.coe.int/t/e/Cultural%5FCo%2Doperation/Environment/Nature%5Fand%5Fbiological%5Fdiversity/Nature%5Fprotection/sc22_inf30erev.pdf Date of Access: Aug2014.

Bishop, J.D.K. & Amaratunga, G.A.J. 2008. Evaluation of small wind turbines in distributed arrangement as sustainable wind energy option for Barbados. Energy Conversion and Management, 49:1652-1661.

Blignaut, J.N., Mabugu, R.M. & Chitiga-Mabugu, M.R. 2005. Constructing a Greenhouse Gas Emissions inventory using energy balances: the case of South Africa: 1998. Journal of Energy in Southern Africa, 16:105-116.

Blyth, W., Bradley, R., Bunn, D., Clarke, C., Wilson, T. & Yang, M. 2007. Investment risks under uncertain climate change policy. Energy Policy, 35:5766-5773.

BMU (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety). 2011. Renewably employed: Short and long-term impacts of the expansion of renewable energy on the German Labour Market. Berlin Germany. http://www.germany.info/contentblob/3179136/Daten/1346894/BMU_RenewablyEmployed_DD.pdf Date of Access: Apr 17, 2014.

Bodde, D.L. 1976. Riding the experience curve. Technology Review.

Booker, J., Mellor, P., Wrobel, R. & Drury, D. 2010. A compact, high efficiency contra-rotating generator suitable for wind turbines in the urban environment. Renewable Energy, 35(9):2027-2033.

Borup, M., Brown, N., Konrad, K. & Lente, H. Van. 2006. Technology analysis and strategic management the sociology of expectations in Science and Technology, 37-41.

Botha, P. 2014. Personal Communication with Peet Botha, Conscius Consultants.

Botha, T. 2015. Personal Communication with Thys Botha, Tlokwe City Council.

Bouffard, F. & Kirschen, D.K. 2008. Centralised and distributed electricity systems. Energy Policy, 36:4504-4508.

Bowen, A.J., Zakay, N. & Ives, R.L. 2003. The field performance of a remote 10 kW wind turbine. Renewable Energy, 28:13-33.

Bowen, A., Huskey, A., Link, H., Sinclair, K., Forsyth T., Jager D.,et al 2009. Small wind turbine testing results from the National Renewable Energy Laboratory. In Wind Power 2009, Chicago, Illinios, USA, 4-7 May 2009.

Bratt, C., Liang, J. & Fiorino, D.J. 2013. The implications of policy stability for renewable energy innovation in the United States, 1974–2009. The Policy Studies Journal, 41; 1

Brealey, R.A. & Myers, S.C. 1997. Princípios de Finanças Empresariais 5a ed.. Lisboa: McGraw-Hill.

Brockington, R.B. 1993. Financial Management 6th ed. London: DP Publications Ltd.

Brosius, W. (2013). Feasibility Study for Wind Power at SAB Newlands. Stellenbosch: US. (Dissertation - MEng).

Brown, N. & Michael, M. 2003. A sociology of expectations: Retrospecting prospects and prospecting retrospects. Technology Analysis & Strategic Management, 15(1):3–18.

Burnett, J.W. 2015. Moving to a Free Market Agriculture Policy. On behalf of Americans for Limited Government Foundation.

Burton, T., Sharpe, D., Jenkins, N. & Bossanyi, E. 2001. Wind Energy Handbook. Chichester: Wiley.

Butler, K.C. & Joaquin, D.C. 1998. A note on political risk and the required return on Foreign Direct Investment. Journal of International Business Studies, 29:599-607

Buys, A. 2007. Measuring Innovation. Essays in Innovation, 2:52-54

California Public Utilities Commission (CPUC). 2010a. Summary of Feed-in Tariff Price.

California Public Utilities Commission (CPUC). 2010b. Feed-in Tariff Price.

California Public Utilities Commission (CPUC). 2013 Net Energy Metering (NEM). http://www.cpuc.ca.gov/PUC/energy/DistGen/netmetering.htm Date of access: Nov. 15, 2014

Carbon Trust. 2008. Small-scale wind energy policy insights and practical guidance. London: WC2A 2AZ

Carson, D., Gilmore, A., Perry, C. & Gronhaug, K. 2001. Case-based Research. (In Qualitative Marketing Research. London: Sage. p.92-112).

Cavaye, A., Perry, C., Evans, M. & Sankaran, S. 2003. MNG 03047 Business research methods: Ethical issues in business research. Southern Cross University, Graduate College of Management.

Celli, M. 2013. Determinants of economies of scale in large businesses - A survey on UE listed firms. American Journal of Industrial and Business Management, 3:255-261

Center for Sustainable Systems, University of Michigan CSS-UM. 2014. Wind Energy Factsheet. Pub. No. CSS07-09.

Chang, T.J. & Tu, Y.L. 2007. Evaluation of monthly capacity factor of WECS using chronological and probabilistic wind speed data: A case study of Taiwan. Renew Energy, 32:1999-2010.

Chang, T.P. 2011. Performance comparison of six numerical methods in estimating Weibull parameters for wind energy application. Applied Energy, 88:272-282

Chicco, G. & Mancarella, P. 2009. Distributed multi-generation: a comprehensive view. Renewable and Sustainable Energy Reviews, 13:535-551.

Choi, C. & Park, Y. 2009. Monitoring the organic structure of technology based on the patent development paths. Technological Forecasting & Social Change, 76:754-768

Christiansen, A.C. 2002. New renewable energy development and the climate change issue: A case study of Norwegian Politics. Energy Policy, 30:235-243.

CoCT. 2012. Net Metering: A Municipal Perspective. City of Cape Town

CoCT. 2014. Residential Electricity Tariff Explanation. Cape Town Electricity Services, City of Cape Town

Connor, P.M**.** 2003 UK renewable energy policy: A review. Renewable and Sustainable Energy Reviews, 7(1):65-82.

Corbin, J. & Strauss, A. 2015. Basic of qualitative research: Techniques and procedures for developing grounded theory. New York: Sage Publications, Inc.

Costa Rocha, P.A., Coelho De Sousa, R., Freitas De Andrade, C. & Vieira Da Silva, M.E. 2012. Comparison of seven numerical methods for determining Weibull parameters for wind energy generation in the Northeast of Brazil. Applied Energy, 89:395-400

Couture, T. & Gagnon, Y. 2010. An analysis of Feed-In Tariff remuneration models: Implications for renewable energy investment. Energy Policy, 38 (2):955-965.

Cowan, R. 1991. Tortoises and hares: Choice among technologies of unknown merit. The Economic Journal, 101:801-814.

Creswell, J.W. 1994. Research design: Qualitative, quantitative, and mixed method approaches. 2nd ed. New York Sage Publication.

Creswell, J.W. 1997. Qualitative inquiry and research design: Choosing among fivetraditions. Thousand Oaks, CA: Sage.

Darrieus, G.J.M. 1931. Turbine having its rotating shaft transverse to the flow of the current. (Patent: US 1835018).

Database of State Incentives for Renewable Energy DSIRE 2007. http://www.dsireusa.org. Date of access: July 7, 2015

David, P. 1985. Clio and the economics of QWERTY. Economic history, 75:332-337

Davidson, O., Hirst, N. & Moomaw, W. 2010. Recommendations to the World Bank Group on lending to South Africa for Eskom Investment Support Project that includes a Large Coal Burning Power Station at Medupi. World Bank, 18 Feb. 2010

Davis, J.A. 2012. Methodological coherence: Establishing a unified research frame. Canadian Journal of Occupational Therapy, 79:131-133. doi: 10.2182/cjot.2012.79.3.1

DeForge, R. & Shaw, J. 2012. Back and fore-grounding ontology: Exploring the linkages between Critical Realism, Pragmatism, and Methodologies in Health and Rehabilitation Sciences. Nursing Inquiry, 19:83-95. doi:10.1111/j.1440-1800.2011.00550.x

De Leeuw, E.D., Hox, J.J. & Dillman, D.A. 2008. International Handbook of Survey Methodology. European Association of Methodology.

Denscombe, M. 1998. The good research guide for small-scale social research projects. Buckingham: Open University Press.

De Oliveira, W.S., Fernandes, A.J. & Gouveia, J.J.B. 2011. Economic metrics for wind energy projects. International Journal of Energy and Environment, 2(6):1013-1038

Department of Energy and Climate Change. 2013. UK Renewable Energy Roadmap Update 2013. London, URN: 13D/259. Date of access: Feb 8, 2015

Department of Energy see South Africa. Department of Energy. 2011. Integrated Resource Plan for Electricity 2012-2030. Government Gazette, 34263:511. Date of access: April 22, 2013

Department of Energy see South Africa. Department of Energy.

Department of Energy **see** South Africa.

Department of Energy **see** South Africa.

Department of Energy IPP **see** South Africa.

Department of Environmental Affairs, DEA **see** South Africa.

Department of Minerals and Energy **see** South Africa

Department of Minerals and Energy **see** South Africa.

Department of Trade and Industry – Small Enterprise Development Agency, Um Jwali Market Research 2012. Research on the Performance of the Manufacturing Sector 2012.

Department of Trade and Industry **see** United Kingdom.

Department of Trade and Industry **see** United Kingdom.

Diab, R.D. 1990. Wind farms in South Africa. Elektron journal, 7(3): 3-5, 25.

Diab, R. 1995. Wind Atlas of South Africa. Pretoria: Department of Minerals and Energy.

Dinica, V. 2003. Sustained diffusion of renewable energy: Politically defined investment contexts for renewable electricity technologies in Spain, the Netherland, and the United Kingdom. Enschede, The Netherlands, Twente University Press.

Distributed Wind Energy Association DWEA. 2013. DWEA Model Zoning Ordinance, Final. http://distributedwind.org/assets/docs/PandZDocs/dwea-model-zoning-ordinance-passed-01-07-12.pdf Date of access: June 3, 2015

Dosi, G. 1982. Technological paradigms and technological trajectories. Research Policy, 11(3):147–162

Doty, A.C. & Martin, A.P. 2013. Assessment of bat and avian mortality at a pilot wind turbine at Coega, Port Elizabeth, Eastern Cape, South Africa. New Zealand Journal of Zoology, 40:1:75-80 http://dx.doi.org/10.1080/03014223.2012.741068 Date of access: November 2013.

Drew, D.R., Barlow, J.F. & Cockerill, T.T. 2013. Estimating the potential yield of small wind turbines in urban areas: A case study for greater London, UK. Journal of Wind Engineering and Industrial Aerodynamics, 115:104-111.

Dulal, H.B., Shah, K.U., Sapkota, C, Uma, G. & Kandel, B.R. 2013. Renewable energy diffusion in Asia: Can it happen without government support? Energy Policy, 59:301-311

Eberhard, A., Kolker, J. & Leigland, J. 2014. South Africa's renewable energy IPP Procurement Program: Success factors and lessons. Washington, DC: Public Private Infrastructure Advisory Facility.

Edkins, M., Marquard, A. & Winkler, H. 2010. South Africa's renewable energy policy roadmaps. For the United Nations Environment Programme Research Project's Enhancing Information for Renewable Energy Technology Deployment in Brazil, China and South Africa. Energy Research Centre, University of Cape Town.

Edwards, J.L., Wiser, R.H., Bolinger, M.A. & Forsyth, T. 2004. Evaluating State Markets for Residential Wind Systems: Results from an Economic and Policy Analysis Tool. Prepared for the
Wind & Hydropower Technologies Program Assistant Secretary for Energy Efficiency and Renewable Energy U.S. Department of Energy. Ernest Orlando Lawrence Berkeley National Laboratory.

Eisenhardt, K.M. 1989. Building Theories from Case Study Research. Academy of Management Review, 14(4):532-550

Elliott, D. 2005. Comparing Support for Renewable Power. Energy and Environment Research Unit, The Open University, Milton Keynes. http://design.open. ac.uk/elliott/documents/ElliottEarthscanhandove2.pdf. Date of access: March 13, 2014

Elliot, D., Schwartz, M., Brower, M. et al. 2011. New Wind Energy Resource Potential Estimates for the United States. Paper presented at the Second Conference on Weather, Climate and the New Energy Economy. NREL/PR-5500-50439.

Energy Saving Trust 2007. Generating the Future: An Analysis of Policy Interventions to Achieve Widespread Microgen Penetration.

Environmental Change Institute 2009. Power from the People - Domestic Microgeneration and the Low Carbon Buildings Programme.

Erlandson, D.A., Harris, E.L., Skipper, B.L. & Allen, S.D. 1993. Doing Naturalistic Inquiry: A Guide to Methods. Newbury Park, CA: Sage Publications, Inc.

eScience 2013. The Localisation Potential of PV and a Strategy to Support Large Scale Roll-Out in South Africa. eScience Associates, Urban-Econ Development Economists, Chris Ahlfeldt. The DTI, WWF, and SAPVIA.

Eskom Holdings SOC Limited. 2012. Eskom Fact Sheet: Generation Plant Mix. Eskom Holdings SOC Limited Integrated Report 2012, Revision 13.

Eskom IDM. s.a. Small Scale Renewable Energy: Pilot Programme.

European Commission. 1994. Externalities of Fuel Cycles "ExternE" Project. Summary Report (Brussels: European Commission).

European Wind Energy Association. 2009a. Wind Energy – The Facts: A Guide to the Technology, Economics and Future of Wind Power. Earthscan, UK and US.

European Wind Energy Association. 2009b. The Economics of Wind Energy.

European Wind Energy Association. 2009c. Wind at Work: Wind Energy and Job Creation in the EU. http://www.ewea.org/fileadmin/ewea_documents/documents/publications/Wind_at_work_FINAL.pdf Date of access: April 25, 2014)

European Wind Energy Association. s.a. Wind Energy – The Facts: Technology (Part 1).

Ferioli, F., Schoots, K. & Van der Zwaan, V.C.C. 2009. Use and Limitations of Learning Curves for Energy Technology Policy: A Component-learning Hypothesis. Energy Policy, 37(7):2525-2535, 2009.

Fidel, R. 1993. Qualitative Methods in Information Retrieval Research. Library and Information Science Research, 15:219–247.

Finlay-Jones, R. 2007. Putting the Spin on Wind Energy: Risk Management Issues associated with Wind Energy Project Development in Australia. Southern Cross University, Lismore, NSW. (DBA Thesis)

Firestone, W.A. 1993. Alternative Arguments for Generalizing from Data as Applied to Qualitative Research. Educational Researcher, 22:16–23.

Fischedick, M. et al. 2000. Nach dem Ausstieg: Zukunftskurs Erneuebare Energien. Stuttgart: Hirzel.

Florio-Ruane, S. 1991. Conversation and Narrative in Collaborative Research. (In Witherell, C. & Noddings, N. eds. Stories Lives Tell: Narrative and dialogue in education, New York: Teachers College Press, p. 234-256).

Forsyth, T. & Baring-Gould, I. 2007. Distributed Wind Market Applications. National Renewable Energy Laboratory, Colorado, US.

Frankel, M. 1955. Obsolescence and Technological Change in a Maturing Economy. American Economic Review, 45:296-319.

Fritz, W.L.O. 2013. Renewable Energy Feed in Tariffs, REBID, SASGI and the Smart Grid. Cape Peninsula University of Technology, Cape Town, South Africa.

Frost and Sullivan, Emergent Energy, 3E, Townsend, N., & Ahlfeldt, C. 2013. Development of a Customised Sector Programme for Small Scale Renewable Energy in South Africa. Task 1-5 Final Report. Prepared for: The Department of Trade and Industry and World Wildlife Fund

Fuglsang, P., Bak, C., Schepers, J.G., Bulder, B., Cockerill, T.T., Claiden, P., et al. 2002. Site SpecificDesign Optimization of Wind Turbines. Journal of Wind Energy, 5:261-79.

Gagliano, A., Nocera, F., Patania, F., Capizzi, A. & Galesi, A. 2012. A Proposed Methodology for Estimating the Performance of Small wind turbines in Urban Areas. Sustainability in Energy and Buildings, SIST 12:539-548.

Gagliano, A., Nocera, F., Patania, F. & Capizzi, A. 2013. Assessment of Micro-wind Turbines Performance in the Urban Environments: An Aided Methodology through Geographical Information Systems. International Journal of energy and Environmental Engineering, 4:43.

Geels, F. W. 2007. Feelings of Discontent and the Promise of Middle Range Theory for STS: Examples from Technology Dynamics. Science, Technology & Human Values, 32(6):627-651.

Giere, G. 1984. Logical Basis of Hypothesis Testing in Scientific Research. http://www.dartmouth.edu/~bio125/logic.Giere.pdf. Date of access: May 14, 2015

Gipe, P. 2004. Wind Power: Renewable Energy for Home, Farm, and Business. Vermont: Chelsea Green Pub. Co., p. 57–57.

Gipe, P. 2011. Testing the Power Curves of Small Wind Turbines. http://www.wind-works.org/articles/Power-Curves.html Date of access: Aug. 15, 2015

Garrad Hassan, G.L. 2012. Assessment of Training and Skills Needs for the Wind Industry in South Africa: Final Report. Document no. 111176-UKGL-R-03.

Glaser, B. & Strauss, A. 1967. The Discovery of Grounded Theory: Strategies of Qualitative Research. London: Wiedenfeld and Nicholson.

Glaser, B.G. 1978. Theoretical Sensitivity. Mill Valley, CA: Sociology Press.

Global Wind Energy Council, Greenpeace International. 2011. Global Wind Energy Outlook 2010. Global Wind Energy Council and Greenpeace International 3rd Edition. http://www.gwec.net/wp-content/uploads/2012/06/GWEO-2010-final.pdf Date of access: October 2013.

Godet, M. & Roubelat, F. 1996. Creating the Future: The Use and Misuse of Scenarios. Long Range Planning, 28(2):164-171.

Goel, R.K. & Ram, R. 2000. Irreversibility of R&D Investment and the Adverse Effect of Uncertainty: Evidence from the OECD Countries. Economics Letters, 71:287-91.

Gokcek, M. & Genc, M.S. 2009. Evaluation of Electricity Generation and Energy Cost of Wind Energy Conversion Systems (WECSS) In Central Turkey. Applied Energy, 86:2731-2739

Gottschall J. & Peinke J. 2008 How to Improve the Estimation of Power Curves for Wind Turbines. Environmental Research Letters, 3(1):015005 (7pp).

Gouws, L. 2014. Personal Communication with Leon Gouws, Kestrel Renewable Energy.

Green, J. & Thorogood, N. 2009 2004. Qualitative Methods for Health Research. 2nd ed. Thousand Oaks, CA: Sage.

Greenpeace, European Photovoltaic Industry Association 2011. Solar Photovoltaic Electricity Empowering the World. Solar generation, 6.

Grigg, C. 2011. Characteristics of a Market Economy. www.edHelper.com Date of access: June 5, 2015

Gross, R., Blyth, W. & Heptonstall, P. 2010. Risks, Revenues and Investment in Electricity Generation: Why Policy needs to look beyond Costs. Energy Economics, 32:796-804

Gross, R., Leach, M. & Bauen, A. 2003. Progress in Renewable Energy. Environment

International, 29(1):105-122.

Grubler, A. 1997. Time for a Change: On the Patterns of Diffusion of Innovation. Laxenburg, International Institute for Applied Systems Analysis (IIASA): 42.

Gsanger, S. & Pitteloud, J. 2014. Small Wind World Report 2014. World Wind Energy Association. Bonn, Germany.

Guba, E.G. 1981. Criteria for Assessing the Trustworthiness of Naturalistic Inquiries. Educational Communication and Technology Journal, 29:75–91.

Guneri, A.F. 2008. Wind Power Energy and Cost Analysis Study in Turkey. Journal of the Energy Institute, 81:181-183.

Gupta, R. & Biswas, A. 2010. Wind Data Analysis of Silchar (Assam, India) by Rayleigh and Weibull Methods. Journal of Mechanical Engineering Research, 2:10-24.

Hagemann, K. 2008. Mesoscale Wind Atlas of South Africa. University of Cape Town. (Thesis – PhD).

Hansen, J.C. & Lennard, C. 2011. A Comparative and Quantitative Assessment of South Africa's Wind Resource – The WASA Project", Windaba September 2011, Cape Town.

Hantelmann-Nawa, C. 2014. Personal Communication with Dr. Carola Hantelmann-Nawa, Gesellschaft für Internationale Zusammenarbeit (South African – German Energy Programme)

Harkonen, J. 2009. Improving Product Development Process through Verification and Validation. University of Oulu, Finland. (Dissertation – Doctoral).

Heagle, A.L.B., Naterer, G.F. & Pope, K. 2011. Small Wind Turbine Energy Policies for Residential and Small Business Usage in Ontario, Canada. Energy Policy, 39:1988-1999.

Hélimax Énergie Inc. 2004. Strategic Study of Wind Energy Deployment in Africa. Prepared for the African Development Bank, March 2004.

Hepbasli, A, & Ozgener, O. 2004. A Review on the Development of Wind Energy in Turkey. Renewable and Sustainable Energy Reviews, 8:257-276.

Hirahara H., Hossain M.Z. & Nonomura, Y. 2005. Testing Basic Performance of a very Small Wind Turbine Designed for Multi-purposes. Renewable Energy, 30:1279-1297.

Hirsch, W.Z. 1956. Firm Progress Ratios. Econometrica, 24:136-143.

Holm, D., Banks, D., Schaeffler, J., Worthington, R. & Afane-Okese, Y. 2008. Renewable Energy Briefing Paper: Potential for Renewable Energy to contribute to National Electricity Emergency Response and Sustainable Development. Pretoria: Department of Energy.

Inglesi, R. 2010. Aggregate electricity demand in South Africa: conditional forecasts to 2030. Applied Energy, 87:197-204.

Inglesi-Lotz, R. & Blignaut, J.N. 2011. South Africa's Electricity Consumption: A Sectoral Decomposition Analysis. Applied Energy, 88:4779-4784.

Industrial Development Corporation of South Africa, IDC. 2012. IDC, German Development Bank Launch GEEF. http://idc.co.za/mediaroom/articles/127-gdc-launch-geef Date of access: Jun. 15, 2014

International Energy Agency, Organisation for Economic Cooperation and Development. 2000. Experience Curves for Energy Technology Policy. Paris.

International Energy Agency. 2010. Key World Energy Statistics. International Energy Agency, Publications. http://www.iea.org/publications/free_new_Desc.asp?PUBS_ID=1199 Date of access: January 6, 2014.

International Energy Agency Wind. 2011. Recommended Practices for Wind Turbine Testing and Evaluation: 12 Consumer Label for Small Wind Turbines. 1st ed. http://www.ieawind.org/index_page_postings/Consumer_ label_RP%2012%20approved.pdf Date of access: August 24, 2013.

International Organization for Standardization. 2005. Guide to the Expression of Uncertainty in Measurement. 2nd ed. ISBN 92-67-10188-9. Geneva, Switzerland.

Ipsos MORI, CAG Consultants. 2011. Evaluation of Low Carbon Buildings Programme. Research Report Undertaken for the Department of Energy and Climate Change.

IRENA. 2012. Renewable Power Generation Costs in 2011. International Renewable Energy Agency Report. Date of access: September 2, 2016

IRENA-GWEC. 2013. 30 Years of Policies for Wind Energy. Date of access: September 19, 2016

Isachsen, A.J., Hamilton, C.B. & Gylfason, T. 1992. Understanding the Market Economy: Aspect of Planning. Oxford: Oxford University Press.

ISET. 2005. Institute für Solare Energieversorgungstechnik e.V. http://reisi.iset.uni-kassel.de/wind/reisi_dw.html Date of access: August 11, 2015

Jacobsson, S., Bergek, A., Finon, D., Lauber, V., Mitchell, C., Toke, D., et al. 2009. EU Renewable Energy Support Policy: Faith or Facts? Energy Policy, 37:2143-2146.

Jamasb, T. & Kohler, J. 2007. Learning Curves for Energy Technology: A Critical Assessment. JEL Classification: O3, Q4. University of Cambridge.

Jones, B. 2014. Small Scale Renewable Energy Generation in the City of Cape Town. 14th Africa Utility Week. Clean Power Africa.

Justus, C.G., Hargraves, R., Mikhail, A. & Graber, D. 1977. Methods for Estimating Wind Speed Frequency Distributions. Journal of Applied Meteorology, 17:350-353.

Kaltschmitt, M., Streicher, W. & Wiese, A. 2007. Renewable Energy - Technology, Economics and Environment. www.intechopen.com/download/pdf/pdfs_id/9334 Date of access: April 3, 2015

Kaplan, S. 1983. Energy Economics: Quantitative Methods for Energy and Environmental Decisions. New York: McGraw-Hill.

Katz, M.L. & Shapiro, C. 1986. Technology Adoption in the Presence of Network Externalities. Journal of Political Economy, 94:822-841.

Kemp, R., Schot, J., et al. 1998. Regime Shifts to Sustainability through Processes of Niche Formation: The Approach of Trategic Niche Management. Technology Analysis and Strategic Management, 10(2):175-195.

Kestrel Renewable Energy. 2015. Provision and Personal Communication with Ayanda Pohlwana on the Initial Costs of Small Wind Turbines Manufactured by Kestrel.

Kgosana, P. 2014. Personal Communication with Phillip Kgosana, South African Bureau of Standards.

Kirke, B.K. 1998. Evaluation of Self-Starting Vertical Axis Wind Turbines for Stand-alone Applications. Griffith University, Australia. (Thesis – PhD),

Kowalczyk, J. 2013. Tracing Emerging Irreversibilities and Divergent Pathways in the Field of Nanosensor Technologies. Utrecht University, Netherland. (Thesis – Masters).

Kosow, H. & Gassner, R. 2008. Methods of Future and Scenario Analysis: Overview, Assessment, and Selection Criteria. German Development Institute. Bonn. http://www.die-gdi.de Date of access: May 2, 2013.

Kruger, A.C., Goliger, A.M., Retief, J.V. & Sekele, S. 2010. Strong Wind Climatic Zones in South Africa. Wind and Structures, 13(1):000-004

Kruyswijk, G. 2014. Personal Communication with Gerrit Kruyswijk, Industrial Development Corporation of South Africa Limited

Kumbernuss, J., Jian, C., Wang, J., Yang, H.X. & Fu, W.N. 2012 A Novel Magnetic Levitated Bearing System for Vertical Axis Wind Turbines (VAWT). Applied Energy, 90(1):148-53.

Kvale, S. 1989. Issues of Validity in Qualitative Research. Lund, Sweden.

Kwartin, R., Wolfrum, A., Granfield, K., Kagel, A. & Appleton, A. 2008. An Analysis of the Technical and Economic Potential for Mid-Scale Distributed Wind. National Renewable Energy Laboratory, Colorado, US. Subcontract Report: NREL/SR-500-44280, December 2008.

Laxson, A., Hand M. & Blair N. 2006. High Wind Penetration Impact on U.S. Wind Manufacturing Capacity and Critical Resources. NREL/TP-50040482. Golden, CO: National Renewable Energy Laboratory.

Lemos, A.D. & Porto, A.C. 1998. Technological Forecasting Techniques and Competitive Intelligence: Tools for improving the Innovation Process. Industrial Management Data System, 98(7):330-337.

Leung, D.Y.C. & Yang, Y. 2012. Wind Energy Development and its Environmental Impact: A Review. Renewable and Sustainable Energy Reviews, 16:1031-1039.

Lewis, J.I. & Wiser, R.H. 2007. Fostering a Renewable Energy Technology Industry: An International Comparison of Wind Industry Policy Support Mechanisms. Energy Policy, 35:1844-1957.

Lichtenthaler, E. 2007. Managing Technology Intelligence Processes in Situations of Radical Technological Change. Technology Forecasting and Social Change, 74(8):1109-1136.

Lincoln, Y.S. & Guba, E.G. 1985. Naturalistic Inquiry. London: Sage.

Loris, N.D. 2014. Free Markets Supply Affordable Energy and a Clean Environment. The Heritage Foundation Backgrounder, No. 2966

Louw, K., Conradie, B., Howells, M. & Dekenah, M. 2008. Determinants of Electricity Demand for Newly Electrified Low-Income African Households. Energy Policy, 36:2814-2820

Lun, I.Y.F. & Lam, J.C. 2000. A Study of Weibull Parameters Using Long-term Wind Observations. Renewable Energy, 20:145-153.

Lund, P.D. 2009. Effects of Energy Policies on Industry Expansion in Renewable Energy. Renewable Energy, 34:53-64.

Luthi, S. 2011. Effective Renewable Energy Policy – Empirical Insights from Choice Experiments with Project Developers. University of St. Gallen. (Thesis - doctoral)

Lyons, M. 2014. Personal Communication with Mark Lyons, Eskom Holdings SOC

Mahembe, E. 2011. Literature Review on Small and Medium Enterprises' Access to Credit and Support in Africa. Compiled by Underhill Corporate Solutions for National Credit Regulator.

Mahmoudi, H., Spahis, N., Goosen, M.F., et al. 2009. Assessment of Wind Energy to Power Solar Brackish Water Greenhouse Desalination Units: A Case Study from Algeria. Renewable and Sustainable Energy Reviews, 13:2149-2155.

Maia, J., Giordano, T., Kelder, N., Bardien, G., Bodibe, M., Duplooy, P. et al. 2011. Green Jobs: An Estimate of the Direct Employment Potential of a Greening South African Economy. IDC, DBSA, Trade and Industrial Policy Strategies.

Mailula, F.T. 2014. Personal Communication with Faith Tumi Mailula, Department of Science and Technology.

Manwell, J.F. et al 2002. Wind Energy Explained. Theory, Design and Application. Chichester, England: Wiley.

Marcus, A. 1981. Policy Uncertainty and Technological Innovation. Academy of Management Review, 6(3):443–48.

Margolis, R. 2002. Understanding Technological Innovation in the Energy Sector: The Case of Photovoltaics. Princeton University. (Disertation – PhD).

Marshall, C. & Rossman, G.B. 1999. Designing Qualitative Research. 3rd ed. Newbury Park: Sage.

Mavromatakis, F. et al. 2004. Modeling the Photovoltaic Potential of a Site. Renewable Energy, 35(7):1387-1390.

Merriam, S.B. 1998. Qualitative Research and Case Study Applications in Education. San Francisco: Jossey-Bass.

Merriam, D.H. 2009. Regulating Backyard Wind Turbines. Vermont Journal of Environmental Law, 10:291-313.

Mehta, M.D. 2002. Nanoscience and Nanotechnology: Assessing the Nature of Innovation in these Fields. Bulletin of Science, Technology & Society, 22(4),:269-273.

Milazi, D.K. 2015. Personal Communication with Dominic Khothatso Milazi, Department of Energy, South Africa

Miles, M. & Huberman, M. 1994. Qualitative Data Analysis: An Expanded Sourcebook. Thousand Oaks: Sage Publications, Newbury Park.

Minderman J., Pendlebury C.J., Pearce-Higgins J.W. & Park K.J. 2012. Experimental Evidence for the Effect of Small Wind Turbine Proximity and Operation on Bird and Bat Activity. PLoS ONE, 7; 7: e41177. doi: 10.1371/journal.pone.0041177

Mintrom, M. 2003. People Skills for Policy Analysts. Washington D.C.: Georgetown University Press.

Mitchell, C., Bauknecht, D. & Connor, P.M. 2006. Effectiveness through Risk Reduction: A Comparison of the Renewable Obligation in England and Wales and the Feed-in System in Germany. Energy Policy, 34:297-305.

Mooz, H., Forsberg, K. &Cotterman, H. 2003. Communicating Project Management: The Integrated Vocabulary of Project Management and Systems Engineering. John Wiley &Sons.

Morse, J.M. 1991. Strategies for Sampling. (In Morse, J. ed. Qualitative Nursing Research: A Contemporary Dialogue Rev. Ed.. Newbury Park, CA: Sage. p. 117-131)

Morse, J.M. 1997. Perfectly Healthy, but Dead: The Myth of Inter-Rater Reliability. [Editorial] Qualitative Health Research, 7:445-447.

Morse, J.M., Barrett, M., Mayan, M., Olson, K. & Spiers, J. 2002. Verification Strategies for Establishing Reliability and Validity in Qualitative Research. International Journal of Qualitative Methods, 1(2), Article 2. 2015. http://www.ualberta.ca/~ijqm/ Date of access: September 25, 2015

Morthorst, P.E. 2004. Cost and Price. Wind Energy – The Facts, Vol. 2. Brussels – Belgium: The European Wind Energy Association.

Mosia, T. 2014. Personal Communication with Thuthukile Mosia, Technology Innovation Agency.

Mostafaeipour, A. 2013. Economic Evaluation of Small Wind Turbine Utilization in Kerman, Iran. Energy Conversion and Management, 73:214-225

Nair, G.S. & Riege, A. 1995. Using Convergent Interviewing to Develop the Research Problem of a Postgraduate Thesis, Proceedings, Marketing Education and Researchers International Conference.

National Electricity Regulator. 2000. Electricity Supply Statistics for South Africa 2000. Pretoria, South Africa: NER.

National Energy Regulator of South Africa. 2009. NERSA Decision on Renewable Energy Feed-In Tariff (REFIT), Media Statement. /http:// www.nersa.org.za/UploadedFiles/News/Media%20Statement%20Announcement%20of%20REFIT%20decision%2031%20March%202009.pdfS Date of access: January 4, 2014.

National Energy Regulator of South Africa. 2011. NERSA Consultation Paper Review of Renewable Energy Feed - In Tariffs.

National Renewable Energy Laboratory. 1997. Dollars from Sense: The Economic Benefits of Renewable Energy. DOE/GO-10097-261 DE96000543. Washington, DC.

National Renewable Energy Laboratory. 2006. Wind Turbine Design Cost and Scaling Model. Technical Report. NREL/TP-500-40566. Golden, CO: National Renewable Energy Laboratory. http://www.nrel.gov/docs/fy07osti/ 40566.pdf. Date of access: April 17, 2014.

Neij, L., Dannemand, A.P., Durstewitz, M., Hoppe-Kilpper, M. & Morthorst, P.E. 2003. Final Report of EXTOOL – Experience Curves: A Tool for Energy Policy Programmes Assessment. Lund, Sweden.

Neij, L. 2008. Cost Development of Future Technologies for Power Generation - A Study Based on Experience Curves and Complementary Bottom-up Assessments. Energy Policy, 36(6):2200-2211.

Nelson, R.R. & Winter, S.G. 1977. In Search of Useful Theory of Innovation. Research Policy, 6(1):36-76

Nelson, R.R. & Winter, S.G. 1982. An Evolutionary Theory of Economic Change. London: Belknap Press of Harward University Press.

Nemet, G.F. 2006. Beyond the Learning Curve: Factors Influencing Cost Reductions in Photovoltaics. Energy Policy, 34:3218-3232.

Nemet, G.F. & Husmann, D. 2012. PV Learning Curves and Cost Dynamics. Advances in Photovoltaics: Part 1. (In Willeke, G.P. & Weber, E.R. eds. San Diego, Oxford, Amsterdam, Academic Press. p. 85-142).

Nenty, H.J. 2009. Writing a Quantitative Research Thesis. International Journal of Education Science, 1(1):19-32.

Nilsson, M. & Noren, S. 2011. Powerful Winds from the East - Explaining the Fast Development of the Chinese Wind Turbine Industry. Chalmers University of Technology, Gothenburg, Sweden. (Thesis - Master of Science in Management and Economics of Innovation).

Ninela, P. 2013. Personal Communication with Phillip Ninela, Department of Trade and Industry, South Africa.

Office of Gas and Electricity Markets – OfGEM. 2010. Feed-in Tariffs.

Organisation for Economic Co-operation and Development OECD, International Energy Agency IEA. 2003. Technology Innovation, Development and Diffusion. COM/ENV/EPOC/IEA/SLT(2003)4.

Orrell, A.C., Rhoads-Weaver, H.E., Flowers, L.T., Jenkins, J.O., et al. 2013. 2012 Market Report on U.S. Wind Technologies in Distributed Applications. Prepared for the U.S. Department of Energy under Contract DE-AC05-76RL01830.

Otto, A. 2013. Personal Communication with Andre Otto, South Africa National Energy Development Institute, South Africa.

Owen, A.D. 2006. Renewable Energy: Externality Costs as Market Barriers. Energy Policy, 34:632-642.

Oyedepo, S.O., Adaramola, M.S. & Paul, S.S. 2012. Analysis of Wind Speed Data and Wind Energy Potential in Three Selected Locations in South-East Nigeria. International Journal of Energy and Environmental. Engineering., 3:1-11.

Ozgener, O. 2006. A Small Wind Turbine System (SWTS) Application and its Performance Analysis. Energy Conversion and Management, 47:1326-1337.

Parker, P. 2008. Residential Solar Photovoltaic Market Stimulation: Japanese and Australian Lessons for Canada. Renewable and Sustainable Energy Reviews, 12(7):1944-1958.

Parkhe, A. 1993. "Messy" Research, Methodological Predispositions and Theory Development in International Join Ventures. Academy of Management Review, 18(2):227-268.

Patton, M.Q. 1990. Qualitative Evaluation and Research Methods. Newbury Park: Sage.

Payne, K. 2014. Personal Communication with Kevin Payne, New Energy Technologies, South Africa

Pederson, T. 2014. Personal Communication with Tom Pederson, Siemens South Africa.

Pegels, A. 2010. Renewable Energy in South Africa: Potentials, Barriers and Options for Support. Energy Policy, 38:4945-4954.

Perry, C. 1998. Structured Processes of a Case Study Methodology for Marketing Research. European Journal of Marketing, 32(9/10):785-802.

Perry, C., Riege, A. & Brown, L. 1999 Realism's Role among Scientific Paradigms in Marketing Research. Irish Marketing Review, 12(2):17-19.

Perry, C. 2001. Case Research in Marketing. Marketing Review, 1(3):303-323.

Polinder, H., Van der Pijl, F.F.A, De Vilder, G.J. & Tavner, P.J. 2006. Comparison of Direct-Drive and Geared Generator Concepts for Wind Turbines. IEEE Trans. Energy Conversions, 21(3):725-733

Pollitt, M.G. 2010. UK Renewable Energy Policy since Privatisation. Electricity Policy Research Group Working Paper 1002, Cambridge Working Paper in Economics 1007.

Poole, S. 2015. Personal Communication with Sean Poole, NMMU/South Africa Wind Energy Association, South Africa

Popp, D. 2010. Innovation and Climate Policy. Annual Review of Resource Economics, 2:275-98.

Prasad, G. 2006. Social issues. (In: Winkler, H. ed. Energy Policies for Sustainable Development in South Africa: Options for the Future. 1st ed. Cape Town: Energy Research Centre).

Prasad, S., Rao, A. & Rehani, E. 2001. Developing Hypothesis and Research Questions. 500 Research Questions.

Pratten, C.F. & Dean, R.M. 1965. The Economics of Large Scale Production in British Industry, an Introductory Study," London: Cambridge University Press.

Price, J. T. 2006. UK Large-Scale Wind Power Programme From 1970 to1990: The Carmarthen Bay Experiments and the Musgrove Vertical-Axis Turbines. Wind Engineering, 30; 3, Multi-Science Publishing Company, Essex.

Querejazu, D. 2012. Small Scale Wind Power for Homes, Farms and Communities. Washington DC: Environmental and Energy Studies Institute.

Ragheb, M. 2015. Economics of Wind Energy. http://mragheb.com/NPRE%20475%20Wind%20Power%20Systems/Economics%20of%20Wind%20Energy.pdf Date of access: Sept 4, 2015.

Rashford, B.S., Macsalka, N. & Geiger, M. 2013. Renewable Energy Investment Analysis: What's the Payback? University of Wyoming Extension.

Refocus. 2002. Small Wind Turbines – The Unsung Heroes of the Wind Industry. www.re-focus.net Date of access: July 30, 2013.

Rehman, S., Sahin, A. 2012. Wind Power Utilization for Water Pumping using Small Wind Turbines in Saudi Arabia: A Techno-Economical Review. Renewable and Sustainable Energy Reviews, 16:4470-4478

Reinecke, J., Leonard, C., Kritzinger, K., et al. 2013. Unlocking the Rooftop PV Market in South Africa. Centre for Renewable and Sustainable Energy Studies.

Reinhard, M. 2015. Personal Communication with Marx Reinhard, 1 Energy Limited.

Renewable UK. 2008. British Wind Energy Association Small Wind Turbine Performance and Safety Standard. http://www.bwea.com/pdf/small/BWEA_SWT_Standard_Feb2008.pdf Date of access: Aug 24, 2013.

Renewable UK. 2010. Small Wind Systems. http://www.bwea.com/small/faq.htmlS. Date of access: April 12, 2014

Renewable UK. 2011. Working for a Green Britain: Employment and Skills in the UK Wind & Marine Industries. http://www.ewea.org/fileadmin/ewea_documents/documents/publications/Wind_at_work_FINAL.pdf Date of access: Apr 26, 2014.

Renewable Energy Policy Network for the 21st Century REN21. 2009. Renewable Energy Actors and Stakeholders. http://www.ren21.net/REPolicies/policy/actors.asp. Date of access: March 22, 2014

Renewable Energy Policy Network for the 21st Century REN21. 2010. Renewables 2010: Global Status Report. Deutsche Gesellschaft fur Technische Zusammenarbeit (GTZ) GmBH, Paris, France

Rhoads-Weaver, H. & Forsyth, T. 2006. Overcoming Technical and Market Barriers for Distributed Wind Applications: Reaching the Mainstream. Paper intended for presentation at Solar 2006 Conference, Denver, CO, July 7–13, 2006.

Rickerson, W., Sawin, J., et al. 2007. If the Shoe FITs: Using Feed-In Tariffs to Meet U.S Renewable Electricity Targets. The Electricity Journal, 20(4):73-86.

Ristow, M. 2014. Personal Communication with Mark Ristow, Adventure Power, South Africa

Rogers, E.M. 1993. Physics for the Inquiring Mind. Princeton, NJ: Princeton University Press.

Roger, E.M. 1995. Diffusions of Innovations. New York, United States of America.

Rolland, S. & Auzane B. 2012. The Potential of Small and Medium Wind Energy in Developing Countries (A Guide for Energy Sector Decision Makers). Alliance for Rural Electrification Position Paper 2012.

Rosenberg, N. 1982. Inside the Black Box: Technology and Economics. Cambridge: Cambridge University Press.

Ross, S.J., McHenry, M.P. & Whale, J. 2012. The Impact of State Feed-In Tariffs and Federal Tradable Quota Support Policies on Grid-connected Small Wind Turbine Installed Capacity in Australia. Renewable Energy, 46:141-147

Rothbard, M.N. 1993. Free Market. University of Nevada, US.

Saeidi D., Sedaghat A., Alamdari P. & Alemrajabi A.A. 2013. Aerodynamic Design and Economical Evaluation of Site Specific Small Vertical Axis Wind Turbines. Applied Energy, 101:765-775.

Sanden, B.A 2004. Technology Path Assessment for Sustainable Technology Development. Innovation: Management, Policy and Practice, 6(2):316-330. http://dx.doi.org/10.5172/impp.2004.6.2.316. Date of access: August 13, 2015

Sanden, B. A. & Azar, C. 2004. Near-Term Technology Policies for Long-Term Climate Targets: Economy Wide versus Technology Specific Approaches. Energy Policy (In press).

Sauter, R. & Watson, J. 2007. Strategies for the Deployment of Micro-generation: Implications for Social Acceptance. Energy Policy, 35:2770-2779.

Sawin, J.L. 2004. National Policy Instruments: Policy Lessons for the Advancement and Diffusion of Renewable Energy Technologies around the World. Thematic Background Paper 3. International Conference on Renewable Energies. Bonn, Germany.

Schulte, K. 2007. Personal communication between Matt Stanberry, ICF International, and Kevin Schulte, Sustainable Energy Development.

Schwerin, A. 2010. Analysis of the Potential Solar Energy Market in the Caribbean. Caribbean Renewable Energy Development Programme (CREDP).

Scientific Working Group on Friction Ridge Analysis, Study and Technology 2001. Validation of Research and Technology. Version 1.0.

Seguro, J.V. & Lambert, T.W. 2000. Modern Estimation of the Parameters of Weibull Wind Speed Distribution for Wind Energy Analysis. Journal of Wind Engineering and Industrial Aerodynamics, 85:75-84.

Seymore, R., Adams, P.D. & Mabugu, M. 2009. The Impact of an Electricity Generation Tax on the South African Economy. Department of Economics Working Paper Series, University of Pretoria.

Shata, A. 2010. Wind Energy as a Potential Generation Source at Ras Benas, Egypt. Journal of Renewable and Sustainable Energy Review, 4(8):2167-73.

Shawon, M.J., El Chaar, L. & Lamont, L.A. 2013. Overview of Wind Energy and its Cost in the Middle East. Sustainable Energy Technologies and Assessments, 2:1-11

Shenton, A.K. 2004. Strategies for Ensuring Trustworthiness in Qualitative Research Projects. Education for Information, 22:63-75.

Sijm, J. 2002. The Performance of Feed- in Tariff to Promote Renewable Electricity in European Countries.

Silverman, D. 2000. Doing Qualitative Research: A Practical Handbook. London: Sage.

Simic Z., Havelka J.G. & Vrhovcak M.B. 2013. Small Wind Turbine – A Unique Segment of the Wind Power Market. Renewable Energy, 50:1027-1036.

Singh, S. 2015. Personal Communication with Sasha Singh, South African Wind Energy Association.

Singh, R.K. & Ahmed, M.R. 2013. Blade Design and Performance Testing of a Small Wind Turbine Rotor for Low Wind Speed Applications. Renewable Energy, 50:812-819.

Smit, T., Junginger, M. & Smits R. 2007. Technological Learning in Offshore Wind Energy: Different Roles of the Government. Energy Policy, 35:6431–6444

Smits, R., Van Merkerk, R., Guston, D.H. & Sarewitz, D. 2008. The Role of TA in Systemic Innovation Policy. Innovation Studies Utrecht (ISU) working paper series.

South Africa. Department of Energy. 2011. Integrated Resource Plan for Electricity 2012-2030. Government Gazette, 34263:511. Date of access: Jan 7, 2014

South Africa. Department of Energy. 2012. Request for Qualification and Proposals for New Generation Capacity under the IPP Procurement Programme, Briefing Note 8, 2 February 2012

South Africa. Department of Energy. 2013. A Survey of Energy-Related Behaviour and Perceptions in South Africa: The Residential Sector. http://www.energy.gov.za/files/media/Pub/DoE-2013-Survey-of-EnergyRelated-Behaviour-and-Perception-in-SA.pdf Date of access: May 20, 2014.

South Africa. Department of Energy. s.a. South African Wind Energy Programme. http://www.energy.gov.za/files/sawep_frame.html Date of access: May 3, 2013.

South Africa. Department of Energy IPP. 2012. IPP Procurement Programme 2012. http://www.ipprenewables.co.za/#page/303 Date of access: Jan 5, 2014.

South Africa. Department of Environmental Affairs, DEA. s.a. Green Fund. South Africa www.sagreenfund.org.za. Date of access: Feb. 6, 2015

South Africa. Department of Minerals and Energy. 1998. White Paper on the Energy Policy of the Republic of South Africa, DME, Pretoria. Date of access: Feb 18, 2014

South Africa. Department of Minerals and Energy. 2006. White Paper on Renewable Energy, DME, Pretoria. Date of access: Jan 8, 2014

Stake, R.E. 1994. Case Studies. (In Denzin, N.K. & Lincoln, Y.S. eds, Handbook of Qualitative Research.Thousand Oaks: Sage p. 236–247).

Statistics South Africa 2012. Standard Industrial Classification of all Economic Activities (SIC). 7th ed. Statistics South Africa, Pretoria. Report No. 09-90-02

Statistics South Africa 2014. General Household Survey 2013. Statistical Release PO318.

Sterzinger, G. & Svrcek, M. 2004. Wind Turbine Development: Location of Manufacturing Activity. Washington, DC: Renewable Energy Policy Project (REPP).

Stimmel, R. 2008. AWEA Small Wind Turbine Global Market Study. American Wind Energy Association, Washington DC, USA.

Stokes, L.C. 2013. The Politics of renewable energy policies: The case of feed-in tariffs in Ontario, Canada. Energy Policy, 56:490-500.

Swanepoel, J.W.H., Swanepoel, C.J., Van Graan, F.C., Allison, J.S. & Santana, L. 2011. Elementary Statistical Methods. 4th ed. South Africa: AndCork Publisher.

Swart, R.J., Raskin, P. & Robinson, J. 2004. The Problem of the Future: Sustainability Science and Scenario Analysis. Global Environmental Change, 14:137-146.

Szewczuk, S. & Prinsloo, E. 2010. Wind Atlas for South Africa (WASA): Project Overview and Current Status. Paper presented at CSIR – Science Real and Relevant Conference 2010.

Szewczuk, S., 2012. Development of a Localisation Strategy for the South African Wind Energy Industry. Paper presented at CSIR – Science Real and Relevant Conference 2012.

Terrell, S.R. 2012. Mixed-Methods Research Methodologies. The Qualitative Report, 17(1):254-280. http://www.nova.edu/ssss/QR/QR17-1/terrell.pdf Date of access:

Thijssen, J.H. & Thijssen, J. 2007. The Impact of Scale-Up and Production Volume on SOFC manufacturing Cost. US Department of energy/National Electric Technology Laboratory.

Thomas, C.D., Cameron, A., Green, R., Bakkenes, M., et al. 2004. Extinction Risk from Climate Change. Nature, 427:145-148. http://www.gbltrends.com/doc/nature02121.pdf. Date of access: Aug 11, 2014.

Thorstensen, L., Chen, J. & Brown, E. 2013. Understanding Renewable Energy Businesses: Aligning Renewable Energy Firms and Economic Developers (A Survey of Renewable Energy Companies). International Economic Development Council, Washington, DC, 20005.

Ticehurst, G.W. & Veal, A.J. 2000. Business Research Methods: A Managerial Approach. South Melbourne: Addison Wesley Longman.

Timilsina, G.R., Kurdgelashvili, L. & Narbel, P.A. 2011. A Review of Solar Energy Markets, Economics and Policies. Policy Research Working Paper 5845. The World Bank Development Research Group Environment and Energy Team.

Ulgen, K. & Hepbasli, A. 2002. Determination of Weibull Parameters for Wind Energy Analysis of Izmir, Turkey. International Journal of Energy Research, 26:495-506.

UNEP 2012. Global Trends in Renewable Energy Investment 2012. Frankfurt: Frankfurt School of Finance and Management.

United Kingdom. Department of Trade and Industry. 2001. The UK Wind Resource: Wind Energy Fact Sheet 8. London, UK.

United Kingdom. Department of Trade and Industry. 2004. The Energy Act 2004. The Stationary Office, London, UK.

United States Department of Agriculture, USDA. 2007. Section 9006: Renewable Energy and Energy Efficiency Program. http://www.rurdev.usda.gov/rbs/farmbill/. Date of access: May 1, 2015.

United States Department of Agriculture, USDA. 2012. USDA FY2014 Budget Summary and Annual Performance Plan. www.obpa.usda.gov/budsum/FY14budsum.pdf Date of access: May 1, 2015

United States Department of Energy. 2008. 20% Wind Energy by 2030: Increasing Wind Energy's Contribution to US Electricity Supply. DOE/GO-102008-2567, July 2008. http://www.osti.gov/bridge Date of access: July 30, 2013.

United States Department of Energy. 2012. 2011 Wind Technologies Market Report.

United States Department of Energy. 2014. 2013 Wind Technologies Market Report.

United States Environmental Protection Agency, EPA. 2013. State and Local Climate and Energy Program: Renewable Energy.

Van Dalen, D.B. 1979. Understanding Educational Research. 4th .ed. New York: McGraw Hill, Inc.

Van Dijk, A.L., Beurskens, L.W.M., Boots, M.G. et al. 2003. Renewable Energy Policies and market Developments. The REMAC 2000 project.

Van Eeden, H. 2014. Personal Communication with Hans van Eeden, Winglette Wind Machines/Palmtree Power Limited.

Van Lente, H., Spitters, C. & Peine, A. 2013. Comparing Technological Hype Cycles: Towards a Theory. Technological Forecasting and Social Change.

Van Merkerk, R.O. & Van Lente, H. 2005. Tracing Emerging Irreversibilities in Emerging Technologies: The Case of Nanotubes. Technological Forecasting and Social Change, 72(9):1094-1111.

Van Merkerk, R.O. & Robinson, D.K.R. 2006. Characterizing the Emergence of a Technological Field: Expectations, Agenda and Networks in Lab-on-a-chip Technologies. Technology Analysis & Strategic Management, 18(3-4):411-428.

Van Niekerk, J.L. 2014. Utility Scale Renewable Energy in South Africa: Recent Growth and Future Prospects. NSTF Energy Workshop. Centre for Renewable and Sustainable Energy Studies, Stellenbosch University

Verbruggen, A. & Lauber, V. 2009. Basic Concepts for Designing Renewable Electricity Support aiming at a Full-scale Transition by 2050. Energy Policy, 37:5732-5743.

Wang, F., Bai L., Fletcher, J., Whiteford, J. & Cullen D. 2008. The Methodology for Aerodynamic Study on a Small Domestic Wind Turbine with Scoop. Journal of Wind Engineering and Industrial Aerodynamics, 96:1-24.

Weigt, H. 2009. Germany's Wind Energy: The Potential for Fossil Capacity Replacement and Cost Saving. Applied Energy, 86:1857-1863.

Weisser, D. 2003. A Wind Energy Analysis of Grenada: An Estimation Using The Weibull Density Function. Renewable Energy, 28:1803-1812.

Whale J. & Malla A. 2011. Scheduling Power Performance Testing at the National Small Wind Turbine Centre. (In Solar 2011, the 49th AuSES Annual Conference, Sydney).

Whale, J., McHenry, M.P. & Malla, A. 2013. Scheduling and Conducting Power Performance Testing of a Small Wind Turbine. Renewable Energy, 55:55-61.

Whelan, B. & Muchapondwa, E. 2009. Enhancing Consumers' Voluntary Use of Small-Scale Wind Turbines to Generate Own Electricity in South Africa. Working Paper 135, University of Cape Town.

Wiesenthal, T., Dowling, P., Morbee, J., et al. 2012. Technology Learning Curves for Energy Policy Support. Reference Report by the Joint Research Centre of the European Commission.

Willcock, T. & Appleby, S. 2009. UK Small-Scale Wind Survey: Installed Capacity, Annual Generation and Market Growth. Prepared by AEA Technology Plc for Department of Energy and Climate Change. Reference number: ED45244 – Issue 2.

Willer, D. 2014. Personal Communication with Dudley Willer, Gundfos South Africa.

Winkler, H. 2005. Renewable Energy Policy in South Africa: Policy Options for Renewable Electricity. Energy Policy, 33:27-38.

Winkler, H., Hughes, A. & Haw, M. 2009. Technology Learning for Renewable Energy: Implications for South Africa's Long-Term Mitigation Scenarios. Energy Policy, 37:4987-4996

Wohlgemuth, N. & Madlener, R. 2000. Financial Support Of Renewable Energy Systems: Investment Vs Operating Cost Subsidies. (In Towards an Integrated European Energy Market, Proceedings of the Norwegian Association for Energy Economics (NAEE) Conference, Bergen/Norway, 31 Aug – 2 Sep 2000).

Wood, D. 2010. Small Wind Turbines for Remote Power and Distributed Generation. Wind Engineering, 34(3):241-254.

Workgreen. s.a. A Green Sector Overview: Small Wind. Midwestern Ontario Regional Green Jobs Strategy. www.workgreen.ca Date of access: Sep 2, 2014

World Commission for Environment and Development. 1987. Brundtland Report. WCED.

World Wide Fund, WWF-SA. 2014. Enabling Renewable Energy in South Africa: Assessing the Renewable Energy Independent Power Producer Procurement Programme. Report Summary, 2014.

World Wind Energy Association. 2012. Small Wind Report 2012. WWEA, Bonn, Germany.

World Wind Energy Association. 2013. Small Wind World Report Update 2013. Bonn, Germany.

Wright, M. 2014. Personal Communication with Marc Wright, Biotherm Energy Limited.

Wright, T.P. 1936. Factors Affecting the Cost of Airplanes. Journal of aeronautical sciences, 3:122-128.

Wright, A.K. & Wood, D.H. 2004. The Starting and Low Wind Speed Behaviour of a Small Horizontal Axis Wind Turbine. Journal of Wind Engineering and Industrial Aerodynamics, 92:1265-1279.

Yin, R.K. 1989. Case Study Research: Design and Methods. Newbury Park: Sage.

Yin, R.K. 1994. Case Study Research: Design and Methods. 2nd ed. Thousand Oaks, Beverly Hills, CA: Sage Publishing. Applied Social Research Methods Series, Vol. 5.

Yin, R.K. 2003. Case Study Research: Design and Methods. 3rd ed. Thousand Oaks: Sage Publications.

Zarefsky, D. 2014. Rhetorical Perspectives on Argumentation: Selected Essays, Argumentation Library 24. Switzerland: Springer International Publishing. DOI 10.1007/978-3-319-05485-8_2.

Zikmund, W. 2000. Business Research Methods. 6th ed. Dryden: Fort Worth.

APPENDICES

APPENDIX A

DOCTORAL RESEARCH IN ENGINEERING DEVELOPMENT AND MANAGEMENT

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT

A Development Path for Small Wind Energy Systems in South Africa

RESEARCH INTERVIEW GUIDE

Introduction

- Compliments
- Name; School; Program of study

Purpose of interview

- Seek your assistance to participate in a research thesis entitled:
- Aim and objectives of the research study

Informed Consent

- No identified risks from participating in this research. Similarly,
- Participation is confidential and completely voluntary.
- The survey is for thesis and professional paper purposes.
- Further information available from the principal researcher or research supervisor.
- Presentation of consent form to participant.

Introduction by Participant

- Name; Organisation; Position

APPENDIX B

LETTER OF INTRODUCTION: OLATAYO IK: PhD. (Development & Management)

Dear Participant

I hereby introduce Kunle Olatayo, a Doctoral (PhD) student at Centre for Research and Continued Engineering Development (CRCED Vaal), North West University, Potchefstroom, under my supervision.

The centre seeks your assistance to participate in a research thesis entitled: . The purpose of this research is to analyse a development path for small wind energy systems (DP-SWES) to install a potential capacity of small wind generation for South Africa, thus partially exploiting the country's estimated wind generation potential of 30.6 GW and the IRP 2010–2030 new-build installed wind capacity commitment scenarios. This study has been approved by North West University's Institutional Review Board.

The study interview was developed to ask you a few questions regarding development of small wind energy system in South Africa. There are no identified risks from participating in this research. Similarly, participation in the interview is confidential, completely voluntary, and you may refuse to participate without consequence. Responses to the survey will only be for thesis and professional paper purposes. To insure safe and proper research procedures, the university institutional review board and regulatory authority (ies) will be granted direct access to the research data without violating the confidentiality of the participants.

Further information regarding the research can be obtained from the principal researcher, Kunle Olatayo (24018597@nwu.ac.za) or research supervisor, Prof. P. W. Stoker (piets@lantic.net; 018-981 3950).

Thank you for your consideration. Your help is greatly appreciated.

Yours faithfully,

PROF P W STOKER
HEAD: CRCED (Vaal)

APPENDIX C

DOCTORAL RESEARCH IN ENGINEERING DEVELOPMENT AND MANAGEMENT

NORTH-WEST UNIVERSITY
YUNIBESITI YA BOKONE-BOPHIRIMA
NOORDWES-UNIVERSITEIT

A Development Path for Small Wind Energy Systems in South Africa

CONSENT TO PARTICIPATE IN THE RESEARCH STUDY

I have read and understood the introductory letter regarding this research project. (Yes) (No)

I am over the age of 18 years and would be pleased to be involved in the project. (Yes) (No)

I agree to the researcher taking hand written notes during the interview. (Yes) (No)

I agree to the use of a recorder for the purpose of the interview. (Yes) (No)

I wish to remain anonymous in any publication arising (Yes) (No)

OR

I consent to being identified in any publication arising, on the understanding that I approve a final version of the material containing my name. (Yes) (No)

______________________________ ______________________________

Name Organisation & Position

______________________________ __________________

Signature Date

APPENDIX D

DOCTORAL RESEARCH IN ENGINEERING DEVELOPMENT AND MANAGEMENT

A Development Path for Small Wind Energy Systems in South Africa

STAKEHOLDER INTERVIEW/QUESTIONNAIRE

Interviewee	
Organisation	
Position	
Date	
Research Aim	
The general aim of this research is to analyse a development path for small wind energy systems (DP-SWES) to install a potential capacity of small wind generation for South Africa, thus partially exploiting the country's estimated wind generation potential of 30.6 GW and the IRP 2010–2030 new-build installed wind capacity commitment scenarios. • Small wind turbines are electricity micro-generation technology rated up to 100kW.	

General

S/N	Research Questions	Response Choices
1	What is your background? Please explain.	• Financial • Engineering • Social Science • Other ……………
2	Do you support small wind turbine as a clean, renewable, and viable source of electricity generation for South Africans? Explain	• Yes • No
3	Have you had any experience with small wind generation/wind energy projects? Please explain.	• Yes • No

Policy

4	Are wind energy development decisions currently influenced by political frameworks in South Africa? Please explain.	• Yes • No
5	Based on experience, please describe the current role of the government in the small wind market. Please explain.	• Satisfactory • Not Satisfactory
6	What degree of importance should the role of government be regarding small wind generation development? Please explain.	• High • Medium • Low
7	What is the current level of the private sector's investment in small wind generation in the country? Please explain.	• High • Medium • Low
8	Are there government incentives for investors and end-users installing small wind generations in South Africa? Please explain.	• Yes • No • Not Aware
9	If yes, are these government incentives adequate and helpful in promoting investments in small wind generations? Please explain.	• Yes • No • Partly

Market/Economic

10	What is the present level of development of the small wind generation market in South Africa? Please explain.	• High • Medium • Low
11	Is there potential for further market expansion of small wind generations in the country? Please explain the market drivers.	• Yes • No
12	Do you think there is adequate public awareness and campaign about small wind generation with respect to market development?	• Yes • No
13	Rank (1 -Not important; 2 -Important; 3 -Very Important), the following reasons why end-users are/may install small wind turbine	• Cost Effective [ ] • Environment [ ] • Independence [ ]
14	Are small wind generation investment decisions in the country influenced by the prevailing economic factors? Please explain.	• Yes • No
15	Will the selling price of small wind generation influence your investment decision? Please explain.	• Yes • No
16	Are there economic and environmental benefits of small wind developmental projects? Please explain.	• Yes • No

Technology

17	What is the present level of technology development/local manufacture of small wind turbine in South Africa? Please explain.	• High • Medium • Low
18	How do you rate the production of small wind technology in the country in terms of standards and certification? Please explain.	• High • Low • None
19	Do you think there is (or can there be) availability of adequate and effective skills development and training for small wind generations in the country? Please explain.	• Yes • No
20	Rank (1 -Not important; 2 -Important; 3 -Very Important) in order of importance, the following challenges currently facing the South African wind industry. Please explain.	• Political [ ] • Economic [ ] • Technology [ ]

Notes

APPENDIX E

DOCTORAL RESEARCH IN ENGINEERING DEVELOPMENT AND MANAGEMENT

A Development Path for Small Wind Energy Systems in South Africa

QUESTIONNAIRE FOR SMALL WIND DEVELOPMENT PATH VALIDATION

Name	
Organisation	
Position	
Education/Experience	
Date	
Objective	

To confirm and establish that the solutions proposed (to overcome the limitations identified) and the results obtained in the development path for small wind energy systems are valid and feasible, and the systems can practically contribute to the energy portfolio of South Africa.

The limitations to the viability and future growth of the sector, as revealed by this study include:

- Insufficient financial incentives
- Policy uncertainty
- Poor administrative processes
- High investment costs
- Uncompetitive LCOE
- Absence of plan/path to a free competitive market and sustainable development

The proposed development path presented two paths to overcome these limitations, termed the advanced-growth and moderate-growth development path.

The advanced-growth development path is incentive-driven, which proposed the granting of investment capital subsidy (grants or loan) to consumers, as a near-term temporary market-pull solution to reduce high up-front costs' burden, stimulate demand and realise quick growth of the small wind sector in the country.

The moderate-growth development path, which involved the application of the learning and scale effect mechanisms, is a long term solution to achieve cost reduction of the system, a free and competitive market, commercial viability, and sustainable growth of the sector.

Advanced-Growth Development Path

***Q1*. The advanced-growth development path proposed the granting of investment subsidy (grant or loan) to consumers, as a near-term temporary solution, to reduce the high up-front costs' burden being encountered in the purchase of small wind systems in the country? In your experience, is there a relationship between granting investment subsidy and reduction in the burden of high up-front costs?**

***Q2*. In your view, would this granting of investment subsidy to consumers stimulate demand and kick-start the rapid growth of small wind market in the country?**

Q3*. The study estimated the amount of investment capital subsidy (grant or loan) that can be offered to consumers at different locations considered in the country. These amount (% of investment cost) (in the research study) were computed using the investment cost of generation per kW of rated capacity approach.** ***From experience, are these amounts acceptable for consumers, and feasible to cause market-pull?

Q4*. The study projected the small wind cumulative installed capacity under the advanced-growth path, where investment subsidies are granted. These projections (in the study) at growth rates of 35%, 30%, 25% for the periods 2016-2020, 2021-2025, and 2026-2030 respectively, are based on industry professionals' contributions, historical growth pattern of SWT and solar PV industry with such support policy, and the assumption that the subsidy proposed will be supported by simplified cost-effective administrative measures, marketing, public awareness, and policy stability.** ***In your view, are these growth projections feasible and achievable in the country, or simply ambitious?

Moderate-Growth Development Path

Q1. The moderate-growth development path proposed the establishment of technology-push policies (supports for R&D, learning effect, and manufacturing scale-up) to achieve cost reduction and competitiveness of the system.   ***From your experience, will cost reduction of the systems make them competitive with other renewable technologies, less needy of market-pull (financial) incentives for sustenance in the future, and further realise long-term sustainable growth of the sector in South Africa?***

Q2. Supports for R&D, learning effect, and manufacturing scale-up are cost-competitive incentive mechanism proposed by this study to achieve cost reduction of the small wind energy systems.   ***In your experience, are these proposed mechanisms applicable to small wind energy systems and the expected cost reductions feasible in the country?***

Q3. The study applied the learning curve to model the outcome of the cost reduction of two selected systems [e300i (1 kW) and e400n (3.5 kW)], and project the future costs of these systems (in the research study) beyond their present value of costs (base year 2015) i.e. R 30,825 and R 72,012 respectively.   ***In your understanding, are these reduced cost projections feasible and achievable in the country, or simply ambitious?***
Q4. The study projected the small wind cumulative installed capacity under the moderate-growth path, where cost reduction and competitiveness of the system are achieved. These growth projections (in the research study), at a growth rates of 20%, 25%, and 35% for the

periods 2016 – 2020, 2021 – 2025, and 2026 – 2030 respectively, are based on the industry professionals' contributions and historical growth pattern of the solar PV industry with such similar situations, and supported by simplified and cost-effective administrative measures, marketing, and public awareness.   ***In your view, are these growth projections feasible and achievable in the country?***

Q5. The study estimated the financial benefits (R 0.036 billion in diesel and coal fuel costs) that would accrue to the country from fuel savings by implementing the moderate-growth development path and actualising the projected installed capacity. This financial benefit estimation was modeled after a study by CSIR Energy Centre, on the actual diesel- and coal-fuel savings and avoided "unserved energy" (Calitz et al, 2005). Investments are required in the proposed cost-competitive incentive mechanisms to make the technology cost-efficient and competitive, and this 'learning investment' includes the cost of R&D, learning effect, and manufacturing scale-up activities conducted by the commercial market actors.   ***In your understanding, should this estimated financial benefit from fuel savings be a motivation for government to financially support the near-term and long-term paths to future development of the small wind sector in the country?***

APPENDIX F

List of Interviewees

▪ **Department of Energy**

Dominic Khothatso Milazi, Project Manager: Renewable Energy Initiatives (wind energy)

▪ **Department of Trade and Industry**

Phillip Ninela, Deputy Director: Renewable Energy (Industrial Development: Policy Div.)

▪ **Department of Science and Technology**

Tumi Mailula, Deputy Director: Hydrogen and Energy

▪ **Eskom SOC**

Mark Lyons, Programme Manager (Wind Fleet)

▪ **Technology Innovation Agency**

Thuthukile Mosia, Investment Case Specialist (Energy)

▪ **Industrial Development Corporation**

Gerrit Kruyswijk, Industry Champion

▪ **South African National Energy Development Institute (SANEDI)**

Andre Otto, Consultant/WASA Project Manager

▪ **South African Bureau of Standards (SABS)**

Phillip Kgosana

▪ **Tlokwe Municipal Council, North West**

Thys Botha, Engineering Technician

▪ **South Africa Wind Energy Association**

Sasha Singh, Director at Edward Nathan Sonnenbergs

▪ **Gesellschaft für Internationale Zusammenarbeit (South African–German Energy Programme)**

Dr. Carola Hantelmann-Nawa, Development Advisor on RE to the Eastern Cape Government

▪ **Conscius Consultants**

Peet Botha, Director

▪ **Kestrel Renewable Energy Limited**

Leon Gouws, Director (Sales and Marketing)

▪ **Kestrel Renewable Energy Limited**

Ayanda Pohlwana

▪ **Winglette Wind Machines/Palmtree Power Limited**

Hans van Eeden, Managing Director

▪ **Adventure power**

Mark Ristow, Business Development Manager

▪ **Biotherm Energy**

Marc Wright, Senior Associate/Technical Manager

▪ **Siemens South Africa**

Tom Pederson, Director (Wind Power)

▪ **1 Energy Limited**

Marx Reinhard, Managing Director/Founder

▪ **Grundfos South Africa**

Dudley Willer, Manager (Knowledge)

▪ **New Energy Technologies**

Kevin Payne, Managing Director/Founder

APPENDIX G

Professional Comments on the Research Study

"It is a well-written document and the content is simple to follow and understand.......Expected cost reduction, proposed mechanisms, and capacity projections are feasible and achievable"

- **Tumi Mailula, Deputy Director, Department of Science and Technology**

"A well-structured and clear document. I like the approach with two opposite hypothesis. I am not surprised by the conclusions that it is economically unviable to use small wind turbines in ZA."

- **Tom Pederson, Director (Wind Power), Siemens South Africa**

"I have read through your report and I have nothing further to add."

- **Reinhard Marx, Managing Director, 1Energy Limited**

"I support the findings of the thesis with some observations. I agree that we have a substantial wind resource which is a strength but wind is a variable energy source. The potential path for the uptake/promotion of small wind turbines should integrate other renewable e.g. photovoltaic.... Yes, granting of investment subsidy to consumers stimulate demand and kick-start the rapid growth of small wind market in the country as long as the producer not inflating his costs with the granting of the subsidy to the consumer....proposed mechanisms should also be applicable to small wind energy systems with expected cost reductions provided it is managed well. Similar mechanisms applied to other RE seem to have a positive"

- **Andre Otto, WASA Project Manager, SA National Energy Development Institute**

"Your results are self-evident and support our experience."

- **Piet Badenhorst, Senior Project Devt. Mgr., Industrial Development Corporation**

"The document is a very interesting read!..............Granting of investment subsidy would help over the short term. Such a program must be well guided and controlled and only financially feasible projects using tested equipment should be used. The subsidies will create some market pull. The projected small wind cumulative installed capacity under the advanced-growth path, where investment subsidies are granted are achievable. The reduced cost projections are slightly ambitious, achievable. Small wind poses great opportunity for learning, development and job creation and that in a country riddled with energy challenges."

- **Ernie Aylward, CEO/Project Mgr., Stellenbosch Wind Energy Technology**

“A good piece of work. Well done.”

- **Leon Gouws, Director (Sales and Marketing), Kestrel Renewable**

“I agree with the research and think the wind resources are definitely there in SA but the policy and economics needed for industry growth are lacking.”

- **Sean Poole, NMMU/South Africa Wind Energy Association**

“Based on your findings, it is clear that government needs to provide more support (regulation, incentives, R&D funding/skills, training, etc.) to enable successful diffusion of small wind generation systems in South Africa.

- **Thuthukile Mosia, Invest. Case Specialist (Energy), Technology Innovation Agency**

“Expected cost reductions feasible in the country If the market becomes free, absolutely.”

- **Dr. Carola Hantelmann-Nawa, Devt. Advisor on RE to the Eastern Cape Govt**

“Overall it’s a well-constructed work. Well done. Representative and good observations....... Yes to the proposed granting of investment subsidy to consumer as a near-term temporary solution. Typical example was the Eskom subsidy “rebate” for the installation of solar geysers which lowered the upfront costs to the consumer. The estimated amount of investment capital in the region of 25% to 30% seem realistic”

- **Marc Wright, Technical Manager, Bio Therm Energy (Pty) Limited**

APPENDIX H

Certificate of Language Editing

21 March 2016

To whom it may concern

Dear Sir/Madam

This is to certify that I have language edited the doctoral thesis of K.I. Olatayo (st nr 240 185 97) entitled *"A development path for small wind energy systems in South Africa"*. The text was checked for clarity and ease of reading, grammar, spelling and punctuation. No changes were made to the technical content of the text. The changes made were done in track changes and can be accepted or rejected by the author. I am one of the official language editors of the university.

Kind regards

Elma de Kock
Cell: 083 302 5282
Email: elma.dekock@gmail.com