ECONOMIC ANALYSIS OF GRID CONNECTED WIND GENERATION PLANTS IN SOUTH AFRICA

Tamai Hore

A research report submitted to the Faculty of Engineering and Built Environment, University of the Witwatersrand, in partial fulfilment of the requirements for the degree of Master of Science in Engineering

Johannesburg, 16 September 2014

Table of Contents

DECLARATION....iv

ABSTRACT.... v

LIST OF FIGURES....vi

LIST OF TABLES....vii

LIST OF ACRONYMS....viii

ACKNOWLEDGEMENTS....ix

1 THE RESEARCH OVERVIEW.... 1

1.1 Introduction.... 1

1.2 Research objectives.... 3

1.3 Knowledge to be gained.... 4

1.4 Research hypothesis.... 5

1.5 The research methodology.... 5

1.6 Research report structure.... 6

2 THEORY OF WIND ENERGY.... 9

2.1 The Betz Limit.... 11

2.2 Types of wind turbines.... 12

2.3 Advantages and disadvantages of the VAWT.... 13

2.4 Advantages and Disadvantages of the HAWT.... 14

2.5 Power curve of a wind turbine.... 14

2.6 Annual wind speed distribution.... 15

2.7 Annual energy distribution.... 16

2.8 Concluding remarks.... 17

3 RENEWABLE ENERGY POLICIES AND SUPPORT SCHEMES USED IN EUROPE 18

3.1 Types of renewable energy support schemes.... 18

3.1.1 Feed in Tariffs.... 19

3.1.2 Premium.... 19

3.1.3 Quota obligation.... 19

3.1.4 Tax Incentives.... 20

3.1.5 Fiscal incentives.... 20

3.1.6 Tendering or bidding or auctions scheme.... 21

3.2 Analysis of support schemes used for wind energy in European countries.... 22

3.2.1 Development of renewable energy in Germany.... 23

3.2.2 Development of wind energy in Spain 25
3.2.3 Development of wind energy in Denmark 26
3.2.4 Development of wind energy in United Kingdom 26
3.2.5 Development of wind energy in China 28
3.2.6 Development of wind energy in India 28
3.3 Concluding Remarks 29
4 DEVELOPMENT OF WIND ENERGY IN SOUTH AFRICA 30
4.1 Barriers to wind energy in South Africa 31
4.1.1 Electricity market structure 31
4.1.2 Grid access 32
4.1.3 Tariffs 33
4.1.4 Societal acceptance 34
4.1.5 Administrative barriers 34
4.1.6 Financial 35
4.1.7 Skills 35
4.2 Support schemes considered by South Africa 35
4.2.1 Overview of the REFIT scheme designed by NERSA 36
4.2.2 Why REFIT was abandoned 37
4.2.3 Overview of the bidding scheme designed by the DoE 39
4.3 Concluding remarks 40
5 FACTORS THAT DETERMINE THE ECONOMICS OF WIND GENERATION 42
5.1 Electricity production - Wind resources 42
5.1.1 Evaluation of wind resources in South Africa. 43
5.2 Capital cost/ Investment cost 47
5.2.1 Prices of wind turbines 48
5.2.2 Grid connection cost 49
5.2.3 Cost of balance of plant 50
5.2.4 Project development costs 50
5.3 Finance costs / Discount rate 51
5.4 Operation and Maintenance (O&M) Cost 52
5.5 Lifetime of turbines 53
5.6 Concluding remarks 53
6 EVALUATION OF REBID SCHEME 54

6.1 Rule of Law, Renewable Energy Policy and Regulatory Environment 54
6.2 Social acceptance and participation of all role players from an early stage............... 55
6.3 Technology 56
6.4 Wind resources (Sites chosen by IPPs).. 57
6.5 Capacity allocation and Tariffs under REBID 58
6.6 Capital investment cost.. 59
6.7 Operation and maintenance costs 60
6.8 Grid connection.. 60
6.9 Concluding remarks.. 61
7 LEVELISED COST OF ELECTRICITY (LCOE) FOR WIND 63
7.1.1 Capital cost 64
7.1.2 Discount rate 64
7.1.3 Capacity Factor 67
7.1.4 Life cycle of the project 67
7.1.5 Annual Operation cost 67
7.2 LCOE calculation methodologies... 67
7.2.1 The results 70
7.2.2 Sensitivity analysis... 71
7.3 Limitation of the model used to calculate the LCOE 72
7.4 Concluding Remarks.. 73
8 CONCLUSION 74
9 REFERENCES 76

DECLARATION

I declare that this research project is my own unaided work. It is being submitted for the Degree of Master of Science in Engineering to the University of the Witwatersrand Johannesburg. It has not been submitted before for any degree or examination to any other University

____

____________________Day of____________________Year______________________

ABSTRACT

South Africa's Integrated Resource Plan (IRP2010) has an allocation of 1850MW for wind generation out of the 3725MW that should be generated from renewable energy. Procurement of this renewable energy was to be done through the Renewable Energy Feed-In Tariffs (REFIT). The National Energy Regulator of South Africa (NERSA) was given the mandate by the Department of Energy (DoE) to determine REFIT tariffs that are enough to attract investors and that would enable sustainability of renewable energy projects in South Africa. NERSA successfully completed the determination of sustainable REFIT rates in 2009. However, the DoE announced in 2010 that it would no longer procure the renewable energy through the REFIT programme, but instead, opted for the bidding process. The DoE believed that a competitive bidding process would bring in more economic value than the REFIT process. This research will explore different support schemes used to introduce renewable energy. More emphasis will be given to the evaluation of the economic benefits of procuring electricity from grid connected wind generation through the REFIT programme versus the bidding process. It also aims to evaluate the success rate of REFIT programmes versus the bidding programmes by benchmarking with international countries that successfully rolled out renewable energy. Finally, the economics of wind generation in South Africa will be evaluated by calculating the Levelised Cost of Energy (LCOE) in South Africa using the parameters from the Renewable Energy Bidding (REBID) programme and a conclusion on the sustainability of wind energy in South Africa will be made.

LIST OF FIGURES

Figure 1: HAWT and VAWT configurations 13
Figure 2: Power curve of a wind turbine 15
Figure 3: Weibull curve 16
Figure 4: Estimated Annual Energy Distribution curve 17
Figure 5: Renewable Energy Support Schemes used in European Countries 22
Figure 6: Cumulative wind installation in Germany 24
Figure 7: Performance of UK’s auction scheme 27
Figure 8: Electricity price path in South Africa 33
Figure 9: Diab's wind atlas map 43
Figure 10: Hagemann's wind atlas map (bottom) 44
Figure 11: Location of wind mast 45
Figure 12: Large scale high resolution wind resource map of South Africa 46
Figure 13: European wind Atlas 47
Figure 14: Capital cost of an onshore wind farm 48
Figure 15: Wind turbine prices by date of delivery (Euro/MW) 49
Figure 16: Pie Chart showing turbine market share in South Africa 56
Figure 17: Top 10 wind turbines by commissioned capacity in 2012 57
Figure 18: Distribution of wind farms 58
Figure 19: REBID capacity allocation and tariff comparison with REFIT 59
Figure 20: Eskom's existing and planned generation capacity 61
Figure 21: Comparison of REBID LCOE with international benchmarks 71
Figure 22: Variation of LCOE with capacity factor 71
Figure 23: Sensitivity analysis of parameters affecting the LCOE 72

LIST OF TABLES

Table 1: REFIT Tariffs - 2009 36
Table 2 REFIT Tariffs Phase II 37
Table 3: Financial parameters used to calculate discount rate for LCOE 66
Table 4: Financial parameters used to calculate LCOE in European countries 66
Table 5: Parameters used to calculate the LCOE for the base case.. 68
Table 6: Low Case, Base case and high case values used to calculate the LCOE 69

LIST OF ACRONYMS

COD	Commercial Operation Date
COP17	17th Session of Conference of the Parties Conference
CSP	Concentrated Solar Power
DANIDA	Danish International Development Assistance
DBSA	Development Bank of Southern Africa
DCF	Discounted Cash Flow
DEA	Danish Energy Agency
DoE	Department of Energy
ECCR	Economic Carrying Charge Rate
EEG	Renewable Energy Sources Act, 2000 (Germany)
EWEA	European Wind Energy Association
FIT	Feed-In Tariff
HAWT	Horizontal Axis Wind Turbine
IPP	Independent Power Producer
IRENA	International Renewable Energy Agency
ISMO	Independent System and Market Operator
LCOE	Levelised Cost of Energy
MFMA	Municipal Finance Management Act
MYPD	Multi-Year Price Determination
NERSA	National Energy Regulator of South Africa
NFFO	Non-Fossil Fuel Obligation
PFMA	Public Finance Management Act
PPA	Power Purchase Agreement
REBID	Renewable Energy Bidding programme
REC	Renewable Energy Certificate
REFIT	Renewable Feed In Tariff
REFSO	Renewable energy Finance Subsidy Office
ROC	Renewable Obligation Certificate
SANERI	South African National Energy Research Institute
VAWT	Vertical Axis Wind Turbine
WACC	Weighted Average Cost Of Capital
WASA	Wind Atlas for South Africa

ACKNOWLEDGEMENTS

This report would not have been possible without the support, encouragement, crucial advice and guidance from many people.

I would like to thank God for giving me strength and determination to complete this research report.

I acknowledge, with gratitude, my debt of thanks to my project supervisor, Dr John van Coller, for all the useful comments, remarks, support and inspiration during this project.

I am also very much grateful to my wife, parents and family for their support, encouragement and love.

1 THE RESEARCH OVERVIEW

1.1 Introduction

South Africa has a vast abundance of coal resources and Eskom, South Africa's power utility, relies heavily on coal for power generation. About 94%[1] of Eskom's power generation fleet consists of coal-fired power stations which provide low cost electricity. However, there has been an increasing demand for South African coal from the international markets, forcing Eskom to compete with international buyers [1]. There is therefore some risk that coal prices will rise significantly in the near future, thereby increasing the generation cost of coal-fired power stations in South Africa. Furthermore the impact of the resultant gas emissions produced by conventional coal-fired power plants on global climate change is of major concern worldwide. South Africa has already made commitment to reduce its carbon emissions during the 17th session of the Conference of the Parties (COP17) held in Durban from 28 November 2011 to 09 December 2011. Apart from the risks mentioned above, South Africa is facing generation capacity constraints and experienced load shedding in 2008 and 2014, hence it urgently needs to increase its generation capacity to meet the ever growing electricity demand.

Introducing renewable energy in South Africa is a solution to the above challenges as it will reduce South Africa's carbon footprint as well as increasing its security of supply. Renewable energy technologies such as wind and solar photovoltaic can be deployed in a much shorter time than coal-fired power stations. Once operational, there is no fuel cost for wind power plants unlike coal-fired power stations, thereby eliminating the risk of loss of coal supply caused by the increasing global coal demand. The more there is a diversified generation mix, the greater the security of supply.

However the challenge associated with the development of renewable energy projects is that they generally have huge initial capital costs. Furthermore, the Levelised Cost Of Energy (LCOE) from renewable energy is currently higher than electricity from conventional coal-fired power stations. The low cost of electricity from coal in South

[1]Eskom's Visitors brochure, "*Eskom Powering the nation*". Issued by Generation Stakeholder Management and Communication Department, March 2011.

Africa has aggravated this situation and has been the major barrier to the development of renewable energy in South Africa. Moreover, from an investor's point of view, renewable energy projects are considered more risky because of technology or resource uncertainty. For investors to invest in risky projects, they would need a higher return on investment than what they would demand for conventional coal-fired power stations. Governments around the world have therefore developed renewable energy support schemes which either provide more revenue certainty (reducing the risk due to resource uncertainty) or reduce the initial capital cost required (reducing the technology related uncertainty). The most used support schemes are Feed-In Tariff (FIT), Premiums, Tendering and Renewable Energy Obligations.

To be effective, renewable energy support schemes need to be backed up by adequate renewable energy policy frameworks which will attract investors [2, 3]. In South Africa, a renewable energy policy was produced in November 2003 (White Paper on the Renewable Energy Policy [4]). In this policy, the Government acknowledges that South Africa has an abundance of renewable energy resources that can be used to generate renewable energy. However, a balance has to be made between the need for energy security, economic growth, environmental benefits and cost of electricity to the consumers. Affordability of electricity is a key issue in South Africa whose large population did not have access to electricity in the apartheid era. The most appropriate support scheme will therefore be one that will ensure that the electricity remains affordable and that will also complement rural electrification. In the White Paper, the government acknowledged that it cannot fund the renewable energy programme. Support would therefore have to come from international investors, mostly from European and other developing countries that have successfully rolled out renewable energy technologies. What is remaining is therefore designing an attractive renewable energy support scheme for these investors.

Initially, the Department of Energy (DoE) chose the Renewable Feed-In Tariff (REFIT) scheme based on its success rate in European countries, especially Germany, Spain and Denmark. It subsequently appointed NERSA to develop the REFIT scheme that would incentivise the development of renewable energy in South Africa. The chosen technologies were wind, solar photovoltaic, landfill gas, small hydro, concentrated solar photovoltaic (with and without storage), biomass and biogas. In 2009, NERSA completed the development of the REFIT rates as well as the selection criteria which were met with a lot of interest from the international players. However, in 2010, the DoE announced that it was abandoning the REFIT scheme in favour of the bidding process. In 2011, the Minister of Energy determined that 3725 MW will be procured from renewable energy by the DoE through a competitive bidding process and Eskom would be the sole buyer. Of the 3725 MW determined, 1450 MW was allocated to wind. This translates to 38.9% of the total renewable energy to be developed

Since then, there has been a lot of debate into whether the Renewable Energy Bidding (REBID) scheme is the best for introducing renewable energy technologies in South Africa. This concern is partly due to the fact that few countries used this scheme as the primary scheme for supporting renewable energy and the success rate was low.

Of the selected technologies, wind is seen as the most promising in South Africa partly because of its success in European countries and partly because of the available wind resources in South Africa. This research will therefore focus on wind generation since it was allocated the largest chunk of renewable energy to be developed in South Africa. Moreover, wind energy is the fastest growing technology amongst all other renewable energy technologies. In 2012 alone, an estimated 44.95GW of wind power was installed globally, bringing the total global installed capacity to 285.7 GW. For the past five years, global wind power has grown by 17.8% per year [5].

1.2 Research objectives

The economics of wind energy is well known in European countries and a lot of literature on this is available [6]. South Africa however has completely different political, climate, social and macro-economic conditions; hence the need to research into the economics of wind energy in South Africa. Whilst it is true that both the REFIT and the REBID schemes were used in various European countries with some form of success, studies have not been done to determine the most suitable scheme for the South African market.

This research aims to evaluate the economics of wind generation in South Africa. This will be done by looking at various renewable energy support schemes, their merits and demerits in general as well as the success rate in various countries where they were employed. The investigation will also look into the reasons for failure or success of these schemes in various European countries.

The research will also aim to answer the following questions.

- What wind resources are there in South Africa? Are the wind resources sufficient to encourage investment in wind generation in South Africa?
- What is the status of wind development in South Africa and how are the installed plants performing?
- What are the barriers in the development of wind energy in South Africa?
- Why did DoE change from REFIT to the bidding programme?
- What is the economic effect of changing from a REFIT to a bidding programme?
- What effect does the South African bidding process, that is 70% based on price, have on the type and quality of projects to be developed in South Africa?
- What are the key cost drivers of wind generation that one should consider in evaluation of the economics of wind generation?
- How comparable is the price from the bidding process to the international benchmarks?

Finally, the LCOE methodology will be used to determine the major key drivers of the economics of wind energy in South Africa by running sensitivity analysis on the identified cost drivers for wind energy. The data from the DoE's REBID programme, which differs from the one used by European organisations such as the European Wind Energy Association (EWEA) and NERSA's REFIT will be used to calculate the LCOE.

1.3 Knowledge to be gained

At the end of the research, the reader will understand the various factors that affect the wind energy economics in South Africa. Since the wind resources dominate the wind energy economics in any country, the research will evaluate whether the wind resources in South Africa are sufficient to support grid connected generation. Although the study will be focused on the economics of wind energy generation in South Africa, the knowledge gained can be applied to most developing countries especially in Africa.

The reader will also gain an insight into the South African REBID programme, how it was designed to break down barriers to wind energy and how it performed both on capacity installed and prices achieved.

1.4 Research hypothesis

This study is designed to assess the hypothesis that wind generation is economical in South Africa if the REBID programme is used to procure wind energy instead of REFIT. This hypothesis will be tested by using the LCOE methodology to calculate the cost of wind energy in South Africa for different economic parameters such as capacity factors (wind conditions), discount rate, investment costs, operation and maintenance costs and the project lifespan. The LCOE methodology was chosen because it provides a common way of comparing the cost of energy across different technologies. It takes into account total project cost (capital cost, taxes, operation and maintenance cost etc.) over the project lifespan. These costs are then evaluated against the produced electricity over the lifespan of the project to give the cost per unit of electricity. This method therefore provides a way of comparing the cost of wind energy to the cost of conventional coal-fired generation. If the cost of wind generation is higher than the price of electricity on the market, the LCOE methodology may be used to determine the level of support needed for these projects to be viable. It should however be highlighted that the LCOE methodology does not take into consideration the many benefits of renewable energy, such as security of supply and reduction of carbon emissions, which are not normally considered by energy markets when setting the price of electricity.

1.5 The research methodology

This research will look at the theory of wind generation in order to appreciate the factors that affect the economics of wind generation. Once this is done, the development of renewable energy and the policies introduced will be investigated. A conclusion will be made on the success rate of the schemes used based on the amount of wind energy developed. Barriers to the development of wind energy in South Africa will be investigated and an analysis will be done on the best support scheme that would overcome these barriers. Experiences in European and Asian countries on the REFIT and the REBID schemes will be used to evaluate their applicability in the South African market. The success of the South African REBID scheme for wind will be evaluated by analysing the results of the first, second and third bidding rounds that were concluded in 2013.

The LCOE methodology will then be used to calculate the applicable South African cost of wind energy generation using the experiences from the South African renewable energy procurement programme. This method will also be used to analyse how each factor affects the economics of wind energy in South Africa.

1.6 Research report structure

The research report has eight chapters that deal with the different aspects of the research. These different components are necessary to reach the conclusion.

Chapter 1 introduces the research work; defines the research problem, explains the knowledge to be gained as well as the methodology to be used.

Chapter 2 gives the theory of wind energy generation. For one to fully appreciate and evaluate the economics of wind energy generation, one needs to have the basic theory of how electricity is generated from the wind. This chapter explores the different factors that affect the amount of power in the wind and the theoretical amount of that power that can be extracted. It also discusses different types of wind turbines being used, their advantages and disadvantages.

Chapter 3 describes the policies adopted by European and Asian countries to stimulate the development of renewable energy as well as the support schemes used, their success rates, strengths and weaknesses.

Chapter 4 looks at the development of wind energy in South Africa before the REFIT programme. Barriers to the development of renewable energy that existed in South Africa will be identified. All the support schemes used by South Africa since the development of South Africa's Renewable Energy Policy in 2003 will be evaluated to see their impact on the development of wind energy generation until 2009 when the REFIT scheme was initiated. This will be done by looking at the projects developed, their sizes and their performance. The REFIT scheme was abandoned even before it started in favour of the REBID scheme in 2011. These two schemes will be discussed in relation to their applicability in South Africa. The reasons for abandoning the REFIT scheme in favour of the REBID scheme will be explained.

Chapter 5 will identify and evaluate various factors that will determine the economics of wind energy generation in South Africa. Since the wind resources available determine the amount of electricity produced, they dominate the economics of wind energy generation. The distribution of wind resources in South Africa will therefore be given special attention. Site location of a wind farm is normally dependent on wind resources available. In addition to site locations with good wind resources, sites that are close to load centres and the grid are desirable from an economic point of view. Research will be done into the areas in South Africa where there are good wind resources and whether the resources are well documented and available to developers. The location and the amount of the wind resources will be evaluated in relation to the grid and the load centres to determine the economics of wind energy generation.

Chapter 6 evaluates the success of the REBID programme using the results from the first, second and third bidding rounds.

In **Chapter 7**, the LCOE methodology for calculating the cost of wind energy generation will be introduced. This will be used to evaluate the competitiveness of the bid price for the DoE's procurement programme. Moreover, this method will be used to show how each parameter that affects the wind energy economics in South Africa contributes to the LCOE. By running sensitivity analysis using average data from the DoE's bidding programme, the contribution of each parameter to the LCOE and therefore the economics of wind energy generation in South Africa, will be made.

Chapter 8 makes a conclusion on whether wind energy generation is really economic in South Africa. Factors that are instrumental to the success or failure of the deployment of renewable energy in South Africa will be summarised. A conclusion will be formed on whether the REFIT designed by NERSA or the REBID designed by the DoE was the best for South Africa. The method used to evaluate the economics of wind energy generation in South Africa may be used for other developing countries where the barriers are similar. Recommendations on what could also be implemented in South Africa to keep the development of wind energy generation stimulated will be made.

2 THEORY OF WIND ENERGY

Wind turbines convert kinetic energy in the wind to electrical power. Power in a stream of wind passing through a wind turbine is given by equation (1) below [7, 8].

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

where P is the power (Watts);

ρ is the air density (kgm^{-3})

A is the area swept by the rotor blades (m^2)

v is the wind speed (m/s)

Equation (1) shows that power in the wind is a function of air density, swept area by the rotor blades and the wind speed. Of the three parameters, wind speed has the greatest influence on the power that can be generated by the wind turbine. Doubling the wind speed will result in eight times the generated power. This fact highlights the importance of accurately determining the wind speed when selecting a site for a wind farm. Wind speed closer to the ground is lower than wind speed at higher heights above the ground due to friction with the earth's surface, trees and buildings. Even if the difference in speed is minimal, its effect on power is huge due to the cube relationship with power. Accurate estimation of wind speed at turbine hub height is therefore crucial in determining the power that can be produced by a turbine. Equation (2) below shows the relationship of wind speed with height.

$$v_2 = v_1 \left(\frac{h_2}{h_1}\right)^{\propto} \qquad (2)$$

where v_2 is the wind speed at height h_2,

v_1 is the wind speed at height h_1, and

$\propto$ is the ground surface friction coefficient, or wind shear exponent.

The ground surface friction coefficient, $\propto$, depends on the roughness of the ground surface and varies from 0.1 for smooth surfaces such as lakes and oceans to 0.4 for City areas with tall buildings. The increase in wind speed with height as in equation (2) occurs up to a certain height, normally about 450m and then starts to decrease.

Another important fact that can be deduced from equation (1) is that the generated power increases proportionally with the increase in swept area, A. This important fact, coupled with greater wind speed higher above the ground as shown on equation (2), influenced the design of taller wind turbines with larger blades. The largest wind turbine in 2011 has a capacity of 6 MW with a hub height of 90 m and rotor diameter of 126 m [9].

From equation (1), it is also evident that the generated power is directly proportional to the air density. The air density is a function of air composition, temperature and pressure. The air density of dry air and humid air is different. For the purpose of calculating the power that can be generated from the wind, an ideal gas is assumed. This leaves the air density being dependent on temperature and pressure. Equation (3) below shows the relationship between air density, ρ in kg/m^3, pressure, P in N/m^2 or Pascals, R, gas constant, 287.04J/kgK, and temperature, T in Kelvin.

$$\rho = \frac{P}{RT} \qquad (3)$$

The turbine at a particular site (constant pressure) can be subjected to different temperatures, from cold conditions to hot conditions, affecting the air density. Now let us consider temperatures of -15^{0}C (cold condition) and 30^{0}C (hot conditions). The ratio of air densities in these temperatures is calculated using equation (3),

$$\frac{\rho_{cold}}{\rho_{hot}} = \frac{303.15K}{258.15K} = 1.17 \qquad (4)$$

The density of hot cold air at -15^{0}C is 1.17 times that of hot air at 30^{0}C. Assuming that all other conditions stays the same, and using equation (1), the turbine will produce 17% more power in cold conditions than in hot conditions.

Estimating the air density is complicated by the fact that temperature and pressure both depend on elevation above ground. At greater elevations, the air temperature is lower (the higher you go, the cooler it becomes) and the air pressure is lower than at ground level. Air density decreases almost linearly as temperature increases. As the altitude increases above sea level, the temperature decreases and the air density increases. Equation (5) below takes elevation into consideration in calculating the air density [8, 10].

$$\rho(z) = \frac{P_o}{RT} exp\left(\frac{-gz}{RT}\right) = \frac{353.049}{T} exp \ \left(-0.034\frac{z}{T}\right) \qquad (5)$$

where $\rho(z)$ is the air density as a function of altitude, z (kgm^{-3})

P_o is the standard (sea level) atmospheric pressure ($101325Nm^{-2}$)

R is the specific gas constant for air ($287\ Jkg^{-1}K^{-1}$)

g is the gravitational constant ($9.81ms^{-2}$)

T is the air temperature (K)

z is the elevation above sea level (m)

Equation (1) assumes that all the kinetic energy is used to generate electricity, but in practice, the actual energy that can be generated by the turbine is less. Equation (1) may be rewritten to account for efficiency by including an efficiency factor termed the power coefficient C_p. Equation 6 shows the power that can be extracted from the wind taking the turbine efficiency into account [7].

$$\mathrm{P} = \frac{1}{2} C_p \rho \mathrm{A} \mathrm{v}^3 \qquad (6)$$

2.1 The Betz Limit

The turbine does not completely stop the wind. The wind still flows downstream, albeit at a lower speed. The power that can therefore be generated from the wind is actually lower than what is suggested by equation (1). A German scientist, Betz determined that there is a theoretical maximum power that a wind turbine can extract from the wind. This value is termed the Betz limit, C_{pBetz}, and this maximum power, P_{Betz} is given by equation (7) below [10].

$$P_{Betz} = \frac{1}{2}\rho A V^3 C_{pBetz} = \frac{1}{2}\rho A V^3 0.59 \qquad (7)$$

The theoretical maximum is 59% of the wind power.

2.2 Types of wind turbines

There are two types of wind turbines employed in the generation of electricity from wind. These are the Vertical Axis Wind Turbine (VAWT) and the Horizontal Axis Wind Turbine (HAWT). This classification is based on how the blades rotate along their axis. The VAWT blades spin on a vertical axis perpendicular to the ground whilst the HAWT has blades spinning on the horizontal axis parallel to the ground. Of the two types, the HAWT is the most used type for power generation. The number of blades employed varies from one to multi-bladed but three bladed HAWTs are the most common used for power generation. Although single and two bladed HAWTs are cheaper than three bladed HAWTs due to material savings, they have got balancing problems. On the other hand, multi-bladed wind turbines are not normally used for power generation because additional blades require additional cost of material without any additional power being realised from the turbine. From equation (6), power that can be produced by a wind turbine at a site is dependent on swept area and wind speed. Furthermore, the aerodynamic loss of the turbine increases as the number of blades increases. Multi-bladed (with more than three blades) wind turbines will therefore produce less net power than three bladed turbines. Multi-bladed wind turbines are mostly employed for applications that require high starting torque such as water pumping because the torque of a wind turbine increases with the increase in the number of blades.

The HAWT can be further classified according to its orientation to wind direction when operating. Upwind turbines operate facing the wind direction whereas downwind turbines operate facing away from the wind direction. Upwind turbines need a yaw mechanism which rotates the nacelle of the wind turbine in order to keep the blades facing the wind. The downwind turbines do not need a yaw mechanism because the blades are blown away by the wind itself. Upwind turbines are preferred for power generation since the wind strikes the blades first, ensuring equal balancing of blades unlike downwind turbines where some of the wind strikes the nacelle and tower before striking the blades. Figure 1 below shows these two types of turbines [11, 8].

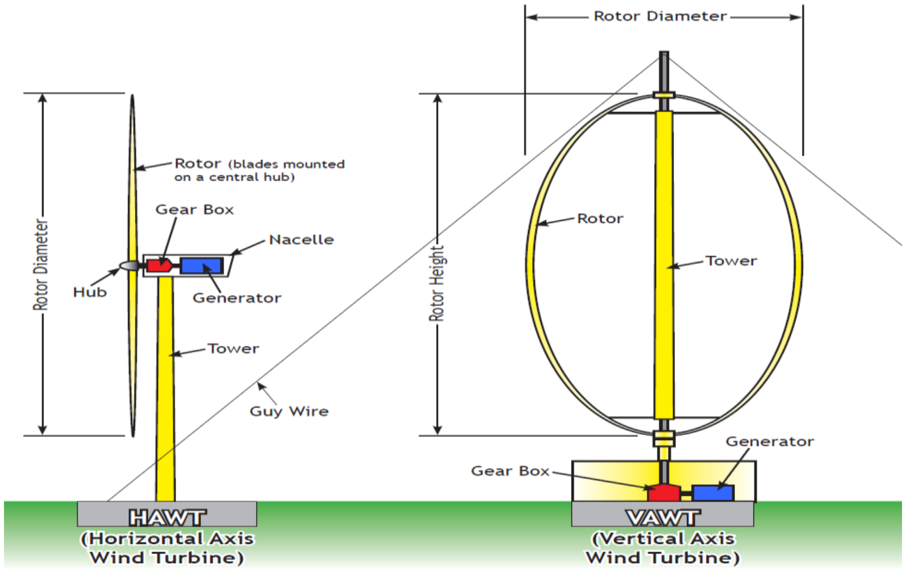


Figure 1: HAWT and VAWT configurations [11]

2.3 Advantages and disadvantages of the VAWT

VAWTs are mounted closer to the ground. The gearbox and the generator, the two components that need regular maintenance due to wear and tear, are therefore closer to the ground. This makes repair work easier as compared to the HAWT whose generator and gearbox are high up in the nacelle. Because of its configuration, the VAWT generates power irrespective of wind direction and does not therefore need a yaw mechanism unlike the upwind HAWT. The VAWT also operates at lower wind speed and produces lower noise as compared to the HAWT. This makes it more suitable for installation in residential areas. The downside of the VAWT is that it is less efficient as compared to the HAWT for the same wind speed. Moreover, the fact that it is installed closer to the ground where there is less wind makes it unsuitable for commercial purposes. The guy wire used to support the turbine increases the wear and tear on the bearings because of the downward force it exerts on these components. Another disadvantage is that the power output varies in the same rotational cycle of the turbine due to the position of blades in relation to the wind direction. The VAWT also needs to be started, unlike the HAWT which starts on its own once the wind speed reaches the cut-in speed.

2.4 Advantages and disadvantages of the HAWT

As mentioned above, the HAWT is more efficient and can produce more power than the VAWT. Variable blade pitch control can be used on HAWTs to increase the power production even further. Its major disadvantage is that it requires higher wind speeds, which are normally found at greater heights. The tall towers required increase the cost of the wind turbines. Another disadvantage is that the upwind HAWT needs a yaw mechanism to align the turbine so that it faces the wind direction all the time. The yaw mechanism increases the cost of the turbine and the cost of maintenance. Although the downwind HAWT does not require the yaw mechanism, the tower and nacelle interfere with the wind before the wind reaches the blades, causing uneven loading of the blades.

2.5 Power curve of a wind turbine

A wind power curve is a curve that describes how much power a particular wind turbine can extract from the wind over a range of available wind speeds. These curves are used to choose the best wind turbine that gives maximum energy yield for a particular site location. Below a certain wind speed (Region 1 on Figure 2), called the cut-in wind speed, the power in the wind is too low to start generating power. The cut-in wind speed is the wind speed at which the wind has enough torque to turn the blades of the turbine and start to produce power. As the wind speed increases, the turbine will continue to produce power according to equation (6). The power generated by the turbine is proportional to the cube of wind speed until the wind speed reaches the turbine's rated wind speed (Region 2 of Figure 2). The rated wind speed is the wind speed at which the turbine is designed to give its maximum power output and above that speed, the power output will be regulated at that value until the cut-out wind speed (Region 3 of Figure 2). This rated power depends on the limit of the wind turbine generator. The cut-out wind speed is the wind speed at which the turbine shuts down in order to prevent damage to the turbine due to excessive stress. This is done by employing the braking system of the turbine. Figure 2 below shows a typical power curve of a wind turbine (blue line) and the power in the wind (yellow line) [12].

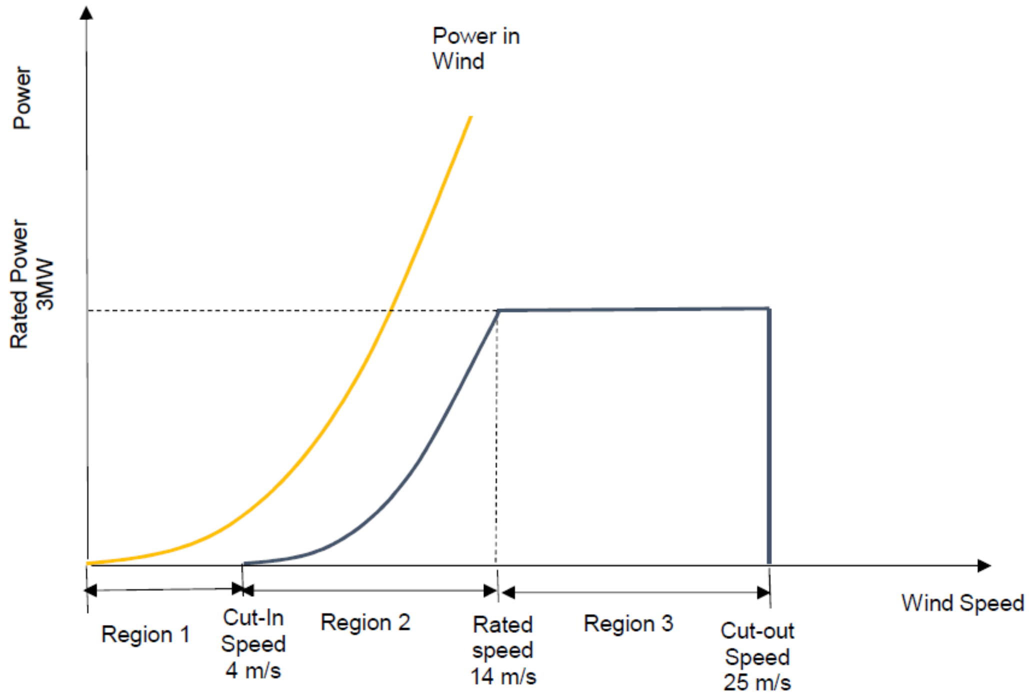


Figure 2: Power curve of a wind turbine [12]

2.6 Annual wind speed distribution

From Figure 2, there is an optimal operating wind speed for each wind turbine. If the wind can blow at that speed all the time, then the turbine would operate at its rated power and produce the maximum possible power. But wind speed changes all the time. The power curve alone would therefore not help in choosing the best turbine for a specific site. An analysis of wind pattern needs to be done over a year or longer period. This would enable an estimation of the number of hours that wind will be blowing at a certain speed in a year. This can then be plotted to produce a Weibull curve. From this curve, the mean annual wind speed is obtained. When choosing a wind turbine for a specific site, a turbine whose rated speed is as close to the mean wind speed is chosen in order to get the maximum electrical output from the turbine per year. Figure 3 below shows an example of a Weibull curve with a mean annual wind speed of 5.5m/s [13]

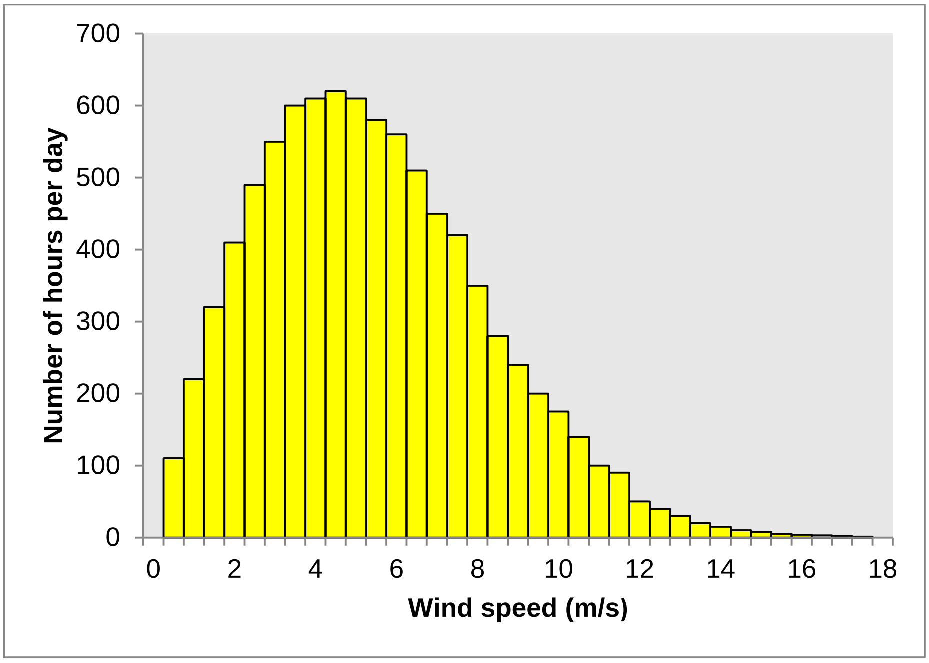


Figure 3: Weibull curve [13]

In choosing the suitable wind turbine, one would therefore have to choose a turbine whose rated speed is 5.5m/s to ensure that the turbine operates at maximum power most of the time. The extreme ends of the Weibull curve would help in choosing the turbine with the appropriate cut-in speed and cut-out speed.

2.7 Annual energy distribution

The aim of covering the theory of wind generation in this project is to understand the economics of wind generation in South Africa. The energy that can be produced by the wind farm is therefore very important. The power curve and the annual energy distribution curve can be used to calculate the annual energy distribution in MWh for each wind speed. This is done by multiplying the power generated by the turbine at each wind speed by the number of hours that the wind blows at that speed in a year and plotting the result on a graph. The sum of this (area under the curve in Figure 4) is the estimated annual energy generated. The estimated annual energy generated is always less than what would have been generated had the turbine been running at rated speed for the whole year. The estimated annual energy generated divided by the energy that would have been generated had the wind been blowing at rated wind speed for the whole year gives the capacity factor of a wind turbine. This capacity factor is normally in the range of 25-40% [13].

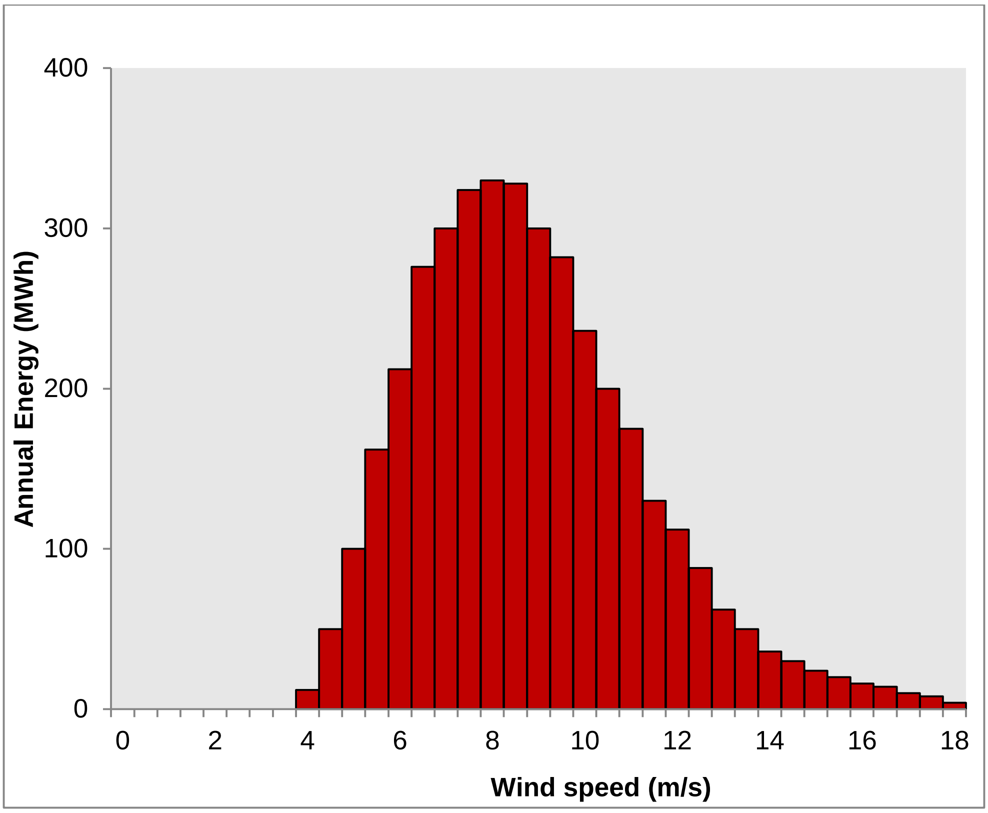


Figure 4: Estimated Annual Energy Distribution curve [13]

2.8 Concluding remarks

The power that is available in the wind is proportional to the cube of the wind speed, the swept area of the rotor blades and the height above the ground. The dependency of available power on the cube of wind speed is a very important factor in deciding the site of the wind farm. A small difference in wind speed between sites has a huge effect on the economics of wind farms at these two sites. Besides wind speed, the swept area and air density are the other factors that determine the amount of power that can be generated from the wind. There are greater wind resources at higher heights above the ground. This makes the HAWT preferred for commercial purposes because they can be designed to be taller with larger rotor diameters to maximise their power production. Today, most onshore wind turbines have a hub height of more than 80 m and rotor diameters of more than 100 m.

3 RENEWABLE ENERGY POLICIES AND SUPPORT SCHEMES USED IN EUROPE

The biggest advantage of wind energy is that, wind, the primary source of energy, is free and will remain so for the project lifetime, unlike coal-fired generation plants where the coal cost accounts for 40% of the production costs, and changes over the lifetime of the project. Unfortunately, wind power plants are capital intensive and need high upfront capital costs to buy the turbines and associated equipment. This in turn makes the LCOE from wind energy high as compared to electricity from coal. Wind energy can therefore develop only if there are clear renewable energy policies which attract investment to this sector. Generally, investors are more willing to invest in wind energy if there is a long-term political and societal commitment towards wind energy. A good renewable energy policy is the one that reduces or eliminates regulatory risks for the permits, authorisations, grid access and licences required to plan, construct, operate and decommission renewable energy projects [9].

Once a good renewable energy policy is in place, it is imperative to design long-term renewable energy support schemes with a sound legal basis. Any changes to the policy or support scheme must be transparent in order to provide predictability and certainty to investors. The recent developments in Spain, Bulgaria and Greece where there are proposals to impose additional tax on renewable energy reduces investor confidence in the renewable energy market, especially if these taxes are introduced after the projects have been developed [14]. Spain and Bulgaria have since implemented the proposed taxes on renewable energy.

3.1 Types of renewable energy support schemes

There are basically six support schemes for renewable energy that are being implemented in the world. Each scheme has its own merits and demerits. It is up to a particular country to choose the scheme that is most suitable to itself. The support schemes are Feed-in-Tariffs (FIT), Premiums, Quota obligations, Tenders (auctions), Tax exemptions and Fiscal incentives. Each scheme is discussed in detail below.

3.1.1 Feed in Tariffs

FIT is the most used support scheme and has been very successful. It is used by 21 out of the 27 European countries [9]. In this scheme, the project developer is guaranteed a pre-set tariff per unit of electricity produced for a specified number of years, normally equal to the lifespan of the plant. This reduces market risks for bankers and funding for the project may be obtained at a lower cost. This ultimately reduces the capital cost of the project. The higher the tariff, the more attractive will be the scheme. The tariff should therefore be carefully set to be attractive enough without letting developers make windfall profits. This may be achieved by periodically adjusting tariffs in line with market changes. However, the review should only be for new projects. The term of the contract may also be made shorter than the lifetime of the plant, just enough to recover the capital cost and to make a reasonable rate-of-return. Because this scheme is based on generated electricity, it encourages concentration of plants in areas with good wind resources. This may be detrimental for the grid operator. However, this may be prevented by setting different tariffs for different areas, taking into consideration the available wind resources.

3.1.2 Premiums

In this scheme, the project developer receives a guaranteed fixed premium on each unit of electricity sold in addition to the income received from electricity sales on the market. This reduces the market risks, just like the FIT, but to a lesser extent. The cost of capital is therefore more than in FIT schemes. Since this scheme depends on electricity market prices, it is mostly used in countries with liberalised electricity market structures. Denmark and the Netherlands are some of countries that use this scheme as the main support scheme [9]. Unlike the FIT, this scheme encourages the developers to generate during peak periods (during which prices are generally higher) in order to maximise profits. By doing so, the developer will also be helping to meet peak demand. The premiums must also be carefully set to avoid excessive profits being made by developers.

3.1.3 Quota obligation

Quota obligations are where the government makes it mandatory for consumers, normally large industrial consumers, or utilities to buy a certain percentage of their electricity needs from renewable energy sources. Penalties are imposed for failure to meet these obligations. Renewable Obligation Certificates (ROCs) that can be traded on the market normally accompany this scheme. This will give an opportunity to the consumers or utilities to supplement their quota requirements from the ROC market should they fail to buy the required renewable energy on the electricity markets. There is higher risk for investors than in FIT and premiums since the developer will be fully exposed to both the electricity and the ROC market risks. The cost of capital will therefore be more as compared to the FIT and the premium. However, its main advantage is that the support can be automatically phased out once the technology manages to compete.

3.1.4 Tax Exemption

Tax may be used as a support scheme for renewable energy projects in two ways, namely investment tax exemption or production tax exemption. Investment tax exemption aims at reducing the capital cost of renewable energy projects, which will ultimately result in lower LCOE from that project. The reduction in capital cost benefits the developer as it makes it easier to raise the required capital whilst the resulting lower LCOE benefits the customers in the form of lower tariffs. In the production tax incentive, income tax is exempted per unit of electricity produced at a predetermined rate. The developers are therefore incentivised to produce more electricity to maximise profits, which is good for energy security of the country. However, the disadvantage of this scheme is that the benefits do not filter down to the consumers. Moreover, in both cases, the developers are still exposed to higher cost of capital because of market risks.

3.1.5 Fiscal incentives

In this scheme, renewable energy projects are funded from the government's annual budget. This is prone to political interference since budgets are negotiated at the political level annually. There is therefore no predictability, as required by developers to make long-term decisions on investing in renewable energy. Because of this, it is usually used as a secondary support scheme.

3.1.6 Tendering or bidding or auctions scheme

Tendering schemes, also known as auctions, are now increasingly popular especially in developing countries. According to IRENA, 30 out of 44 countries that implemented this scheme from 2009 to 2013 are developing countries [15]. In this scheme, the government determines the required capacity. After that, it designs standard long-term contracts for the procurement of renewable energy; thereby providing a guaranteed market for the renewable energy produced. The government would then invite developers to submit bids based on price. Because of competition, the developers normally offer the true bid prices based on cost of generation. The provision of long-term contracts reduces the project risks for the bankers; thereby reducing the cost of capital and ultimately the investment cost of the plant.

The major disadvantage of the tendering system is that it is prone to underbidding. Sometimes bidders bid at very low prices in order to secure the contract, only to realize that they cannot now get funding because of the low return on investment. This may lead to a project being delayed or abandoned. To mitigate this, penalties for late Commercial Operation Dates (COD) and failure to reach anticipated production levels (with reasonable allowances) are normally imposed in the contract.

The second disadvantage is that preparation of tender documents can be expensive and time consuming especially for new and small-scale developers who have limited resources. This scheme is therefore more suitable for large corporations which can finance the initial project costs such as feasibility studies, environmental authorisations and land use permits without any guarantee that the company will win the contract.

Another risk with this scheme is that developers may use sub-standard or cheap technology, compromising the electricity production over the lifespan of the project. This may be prevented at the tendering stage by qualifying bids based on technology to ensure that only those bids which use the required technology are considered.

Prices may also change between bid award and financial close, making the project unviable. This may be mitigated by making provision for adjustment of bid prices in line with financial market indicators such as inflation and currency exchange rates at financial close.

3.2 Analysis of support schemes used for wind energy in European countries

Development of wind energy in Europe started in the 1970s and several support schemes were implemented over the years. The FIT, Feed-In Premiums, Renewable Obligations, Tenders (auctions) and Tax Incentives are some of the schemes employed. Figure 5 below shows the schemes used in Europe by each country [9].

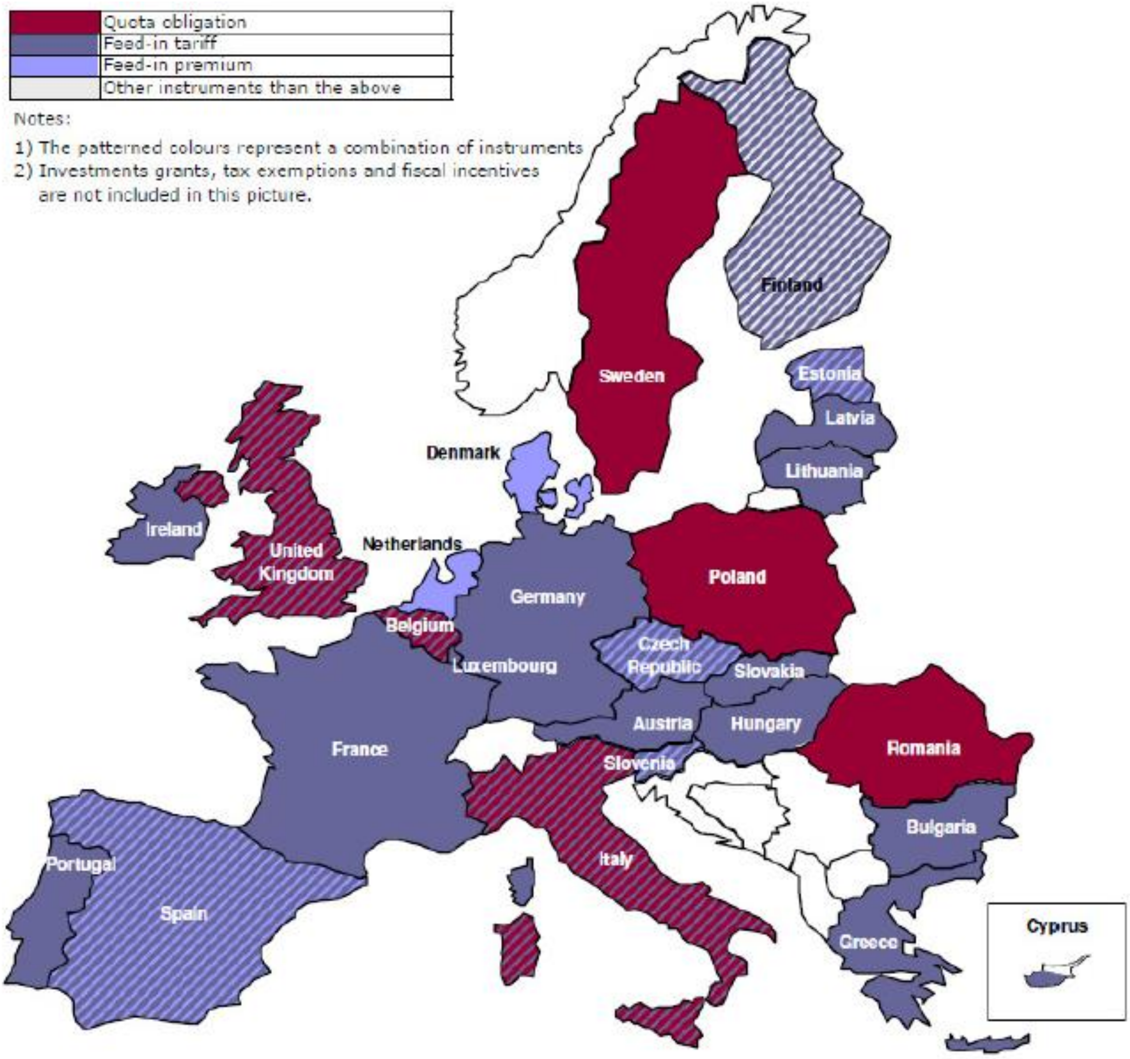


Figure 5: Renewable Energy Support Schemes used in European Countries [9]

Denmark, Germany and Spain are the three pioneering countries for developing wind energy in the European Union. The following section will look at the renewable energy policies and incentive schemes that were used in these countries. China and India are the two developing countries that also have stepped up wind installations in recent years and are now the fastest growing wind markets. Their renewable energy policies and support schemes will be analysed in the following section.

3.2.1 Development of renewable energy in Germany

Before 1973, Germany was heavily reliant on imported oil for its energy needs. In 1973 and 1979, the oil producing nations increased oil prices drastically and reduced exports to some European countries including Germany. This caused shortage of oil in Germany and it prompted Germany to look for other sources of energy which would make it self-sufficient in energy. Germany started using more coal and nuclear for power generation. Renewable energy such as wind was also identified as one of the solutions to the oil crises. In 1979, Germany set up the first special tariff based on avoided cost of generation for the procurement of renewable energy by local utilities. On 26 April 1986, there was a nuclear accident at Chernobyl nuclear Power Plant in Ukraine. This changed Germany's policy on nuclear power stations as the preferred source of electricity and interest in renewable energy was intensified. However, there was slow development of renewable energy because of the low estimated avoided cost of generation. In 1993, Germany moved away from the avoided cost mechanism for supporting renewable energy and introduced the renewable energy feed-in law called Electricity Feed–In Act. This Act provided guaranteed access to the grid and FITs for renewable energy projects. The FIT for wind power was pegged at 90% of the average electricity price. This law was very successful and there was a boom in the installation of renewable energy between 2000 and 2005 [16]. In 2011, another nuclear accident happened, this time at Fukushima nuclear power plant in Japan. This strengthened Germany's support for renewable energy and phasing out of nuclear power stations by 2022. Germany had to increase its renewable energy target to 35% of its energy requirements by 2020 [3, 16]. By 2011, Germany's wind installed capacity was 29060 MW and it is on course to achieve its target. Figure 6 below shows the development of wind energy up to 2011 [9].

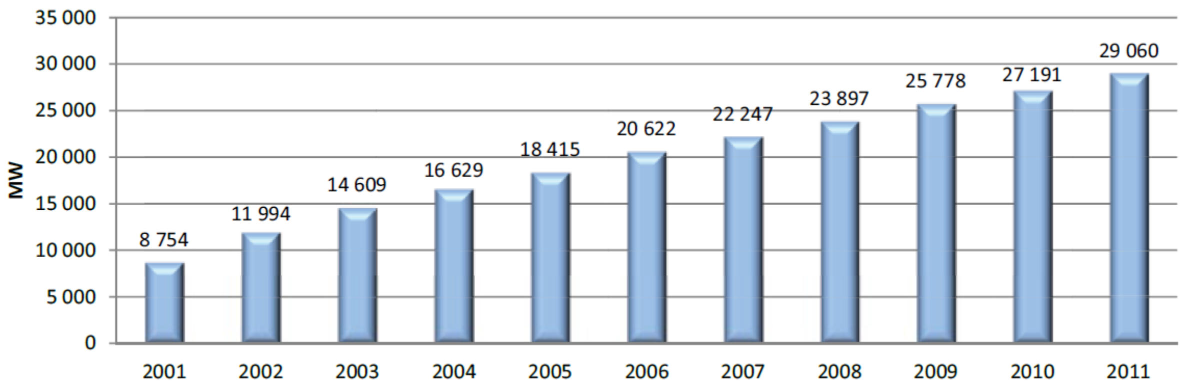


Figure 6: Cumulative wind installation in Germany [9]

In 2000, Germany passed a new law to govern renewable energy called the Renewable Energy Sources Act, 2000 (Das Erneuerbare-Energien-Gesetz or EEG). Under this Act, a FIT was re-designed for renewable energy and the renewable energy projects were given priority access to the grid. It was made mandatory for power utilities to purchase power from renewable energy technologies over 20 years. To ensure that developers do not receive very high profits from this programme without scaring investors, the FIT was fixed for an initial 5 year period and would be adjusted for the remaining 15 years in accordance with wind resources available at that site. From 2002 to 2012, the EEG was amended to account for the technological learning curve by implementing tariff digression for new wind projects. The digression rate was initially fixed at 2% and later revised to 1% [3].

The EEG 2012 was amended again primarily to encourage market growth of offshore wind (which is not discussed in this research report) and to create new options for renewable energy generators to sell electricity into the wholesale electricity market through the introduction of the market premium [14]. The premium is calculated on a monthly basis and is equal to the difference between the feed-in tariff and the reference price. This scheme is even better than the FIT in preventing windfall profits since the premium is calculated monthly based on the monthly average electricity price on the market. The premium may also be phased out automatically once grid parity is achieved.

Because of the high number of wind farms installed in Germany to date and the projected installation, Germany's FIT scheme is normally used as a reference point for encouraging the deployment of renewable energy in general and wind energy in particular. However, when considering this scheme in developing countries, it should be noted that Germany has a strong financial market and skilled workforce that may not be present in developing countries [3].

3.2.2 Development of wind energy in Spain

Spain has the second largest wind installations after Germany. Its cumulative wind installation in 2011 was 21673 MW. Spain introduced its Renewable Energy Plan, 1986, which was reviewed several times until 1994. The main focus of this plan was to show that renewable energy can be employed on a large scale. In 1994, the FIT was introduced through the Royal Decree 2366. In 1997, Spain passed its Electric Power Act 54 /1997, which paved the way for the introduction of a premium scheme. This act also prioritised grid access for renewable energy projects.

The FIT was introduced in 2007 as the main support scheme through Spain's Royal Decree 661/2007. This scheme was operating alongside feed-in premiums. Five projects with a total capacity of 3200 MW were also implemented through concession bidding. Concession bidding was chosen because the scope of work involved building transmission lines. The FIT scheme, the research budget that had been introduced in 1999 and the local content requirement encouraged turbine manufactures to set up manufacturing plants in Spain. Spain is now one of the major turbine suppliers [3].

In February 2013, Spain introduced 6% additional tax on revenue generated from electricity. This tax will be used to fund Spain's FIT budget which had a deficit of €24bn in 2011 [14]. The introduction of additional taxes targeted at a specific industry reduced the confidence of investors. Investors saw it as a way of the government trying to reduce the windfall profits being received by renewable energy developers from FITs. Because there is a strong rule of law in that country, the developers have turned to the courts for recourse. Spain is now facing several lawsuits at the International Court for Arbitration. Besides Spain, Bulgaria and Greece are two other European countries that have announced the introduction of taxes on renewable energy as a way of reducing the profits being realised by developers from the preapproved tariffs.

3.2.3 Development of wind energy in Denmark

After the oil crises of the 1970s, Denmark shifted to nuclear for its energy needs. Due to safety concerns, nuclear was abandoned in 1976 in favour of wind energy. Denmark's first support scheme for wind energy was a tax imposed on electricity. This tax was used to fund research and development of renewable energy technologies. This boosted wind turbine manufacturing in Denmark. By 1980, Denmark was a major exporter of wind turbines [3]. Grants were given to developers for the installation of wind farms, most of which were owned by communities. As an additional incentive, the communities operating wind farms were given tax rebates

The FIT was introduced in 1990. This was based on the market price of electricity and was initially pegged at 85%. Along with the FIT, grid access was made mandatory for renewable energy. As at 2011, Denmark's wind installation was 3 871 MW and it plans to satisfy 50% of its energy requirements from renewable energy by 2020 [3].

3.2.4 Development of wind energy in United Kingdom

Development of renewable energy in the UK started in 1990, soon after the privatisation of the generation companies. The market for renewable energy was created by setting up a Non-Fossil Fuel Obligation (NFFO) scheme, which required distribution companies to buy a certain amount of their power from renewable sources and nuclear at a premium. The Independent Power Producers (IPPs) who wanted to participate in this programme were chosen through an auction system. A fuel levy that had been introduced to all consumers was then used to compensate the distributors for buying non-fossil fuel power at a premium. The government would announce the capacity available for auction and the IPPs would bid. There were five (5) auctions done from 1990 to 1998. In the first two auctions, the preferred bidders were offered the same pre-set price. In the third, fourth and fifth auctions, the contract prices were as per the submitted bid. Although capacity uptake was very good for all auctions, very few projects were realised. This is attributed to unrealistically low bids, especially in the fourth and fifth auctions. The absence of penalties for failure to deliver the project also encouraged non-serious bidders. The other reason was that the preferred bidders were selected before the project is fully planned and all approvals are obtained. Most preferred bidders either failed to get required permits or the process took too long. Because of high population density in the UK, it is not easy to get permits for onshore wind farms [3, 15].

Although the bid response was very good with all allocated capacity being taken, only 4.7% capacity was installed. Figure 7 shows the graphical presentation of the performance of this programme from capacity uptake and price perspective.

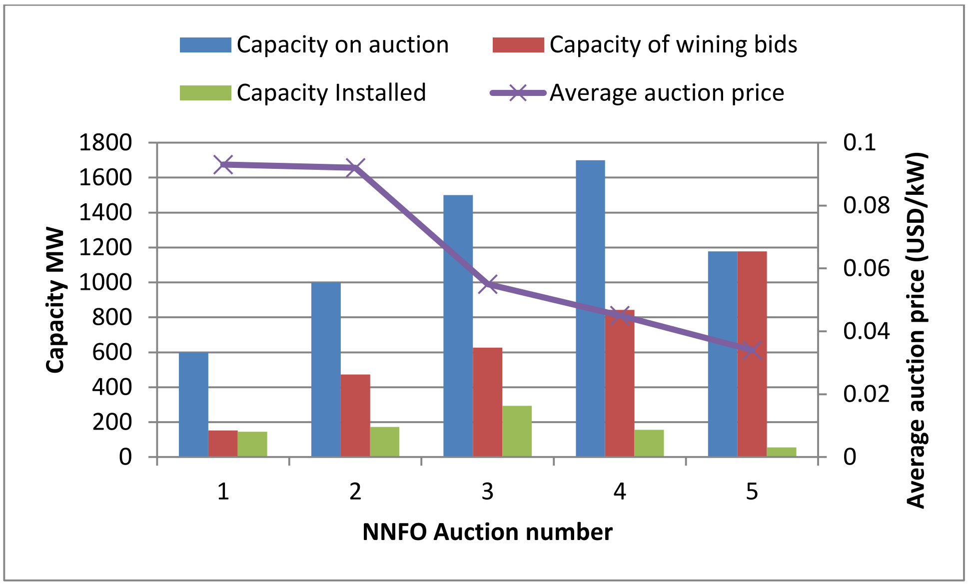


Figure 7: Results of UK's auction scheme[2]

From the year 2000, the UK introduced renewable obligation scheme where all distribution companies were required to buy renewable energy from any technology and get renewable energy points. The points were the same irrespective of technology. This was however changed later and new technologies were allocated more points. UK then introduced trading for Renewable Obligation Certificates (ROC) which could be traded by the distribution companies to meet their required obligation. UK's wind installations grew tremendously from just under 500 MW in 2000 to 5248 MW in 2010 under this scheme [3].

In 2010, UK introduced a FIT scheme for renewable energy technologies up to 5MW. The FIT was different for different technologies. As at 2011, UK's installed capacity was 6540 MW [3].

[2] Drawn using information from [3] and [24]

3.2.5 Development of wind energy in China

China's wind installation has been doubling every year from 2007 to 2010 and now has the highest wind cumulative installation of 62733 MW as at 2011. China has good wind resources that are better than in Germany, Spain and India. [3]. China's initial support scheme for renewable energy was from donor funds and government grants for renewable energy demonstration plants. There were challenges with grid connection and a market for the costly renewable energy produced until 1990 when the government directed the power utilities to ensure grid access and that they had to buy the renewable energy produced. In 2001, China introduced a tendering concession for renewable energy. The tendering selection criteria required the developers to use wind turbines with 70% local materials. This stimulated the local companies to manufacture wind turbines and China has since became a power house in turbine manufacturing with four leading manufacturers in the top five suppliers in 2012. These manufacturers are OEMs, Goldwind, United Power and Snovel [5].

China used its experience in tendering concession to set tariffs for projects awarded out of the tendering scheme in some areas. In 2009, China introduced its FIT programme. The tariffs were designed according to the wind resources available. This encouraged the development of renewable energy throughout the country [3, 15].

3.2.6 Development of wind energy in India

India is in the top five wind energy markets with a total installed capacity of 16 084 MW as at 2011. Grants and donor funds from Danish International Development Assistance (DANIDA) were the first support schemes for wind energy projects. These funds were used mostly for demonstration plants. To facilitate this, India formed a dedicated department called the Department of Non-Conventional Energy Sources. This was later turned into a Ministry. To incentivise private companies into development of wind energy, the state distribution companies were required to buy all renewable energy at agreed rates. The developers would also get tax exemptions on energy sold for the first five years whilst the project gets 100% accelerated depreciation on investment (another type of tax incentive). It is under this scheme that India's wind energy started to grow [3].

In 2003, the Electricity Act was passed into law. This law introduced quota obligations which compelled the electrical distributors to source a certain percentage of electricity from renewable energy sources. It also ensured mandatory grid access to renewable energy. In 2009, India introduced its FIT which differed depending on wind resources.

3.3 Concluding Remarks

Renewable energy policies that show long-term political and societal commitment to renewable energy are the cornerstone of the development of wind energy in any country. They give investors' confidence in the projects and this would reduce the capital cost of installing wind projects. The policies should be periodically adjusted in response to market changes. The most used primary support scheme in the countries studied were the FIT followed by the tendering scheme. Obligations were used as a secondary scheme to create a market for renewable energy. China and Spain imposed local content requirements in their support schemes coupled with research and development to encourage local manufacture of wind turbines. This worked very well, partly because both countries have strong manufacturing industries.

Having discussed the schemes employed in other countries, their success rates and failures, it is imperative to look at the schemes used in South Africa. The next chapter will look at the wind energy development in South Africa before the initiation of REFIT and subsequent change to REBID. Barriers for development of wind energy will be identified and a conclusion made on whether the REBID was the best scheme to overcome these barriers.

4 DEVELOPMENT OF WIND ENERGY IN SOUTH AFRICA

Before the initiation of REFIT and REBID, there were three grid connected wind farms in South Africa, of relatively small sizes. These were the Darling Wind Farm, the Klipheuwel Wind farm and the Coega Industrial Development Zone Wind Farm (Coega).

The Darling wind farm consists of 4 x 1.3 MW turbines and was commissioned in 2008. It is South Africa's first wind farm run by an IPP. It was funded by a grant from the Danish International Development Assistance (Danida), loans from the Development Bank of Southern Africa (DBSA) and the Central Energy Fund (SOC) Ltd as well as equity from the Darling Independent Power Producer (Darlipp). The wind farm has a 20 year power purchase agreement with the City of Cape Town and a wheeling agreement with Eskom. The design capacity factor of the wind farm is 28% but the plant has been performing below that despite measured wind speed being around 6.5 m/s. From February 2009 to June 2009, the wind farm was completely shut down due to contractual disagreements with the turbine manufacturer. This led to the removal of Darlipp as the Operation and Maintenance (O&M) service provider. G7energies was then appointed as the O&M contractor. The problem seems to be lying with the performance of the wind turbines. The company is considering decommissioning the existing turbines and replacing them with newer turbines that are more efficient. These turbines will also be taller so as to exploit better wind resources found at more than 80 m above the ground.

The Klipheuwel Wind Farm has a total capacity of 3.16 MW. It consists of a 66 kW, a 1750 kW and a 750 kW turbine and was commissioned in 2002. This farm was built by Eskom in the Western Cape Province as a demonstration plant and supplies power directly into the Eskom grid. This plant is performing well as expected.

The Coega Industrial Development Zone Wind farm (also known as the Electrawinds wind farm) has one 1.8 MW turbine that was commissioned in 2010. It had a three year power purchase agreement with Nelson Bay Municipality. The owners have since secured a long term contract with Amatola, (Pty) Ltd, a local green energy trader in February 2014.

4.1 Barriers to wind energy in South Africa

Although the support schemes discussed in Chapter 3 were successful in stimulating renewable energy in the European markets, they might not necessarily be effective in the South African market because of the differences in the electricity market structures, political situations, technological advancement and climatic conditions. It is therefore important to identify all barriers to renewable energy in South Africa before choosing the best renewable energy support scheme that would eliminate these barriers.

4.1.1 Electricity market structure

The distribution of electricity in South Africa is dominated by Eskom and the Municipalities. Eskom is responsible for distributing electricity in non-urban areas whilst the Municipalities are mandated by the Constitution of South Africa and the Municipal Finance Management Act (MFMA) to provide all services including electricity in municipal areas (although Eskom still supplies in some municipal areas because of historical arrangements). Whilst there is an opportunity for IPPs to connect directly to municipal networks and sell electricity to these Municipalities, the MFMA imposes two conditions that make investment into wind energy unviable. The first condition is that the Municipality can only buy power from an IPP at a rate that is equal to or lower than the rate at which it buys electricity from Eskom. Since the Municipalities buy electricity from Eskom at bulk or wholesale price, it becomes even more difficult for IPPs to get a viable tariff from the Municipalities. The Coega Industrial Development Zone Wind farm and the Darling Wind farm are good examples of IPPs that are selling to Municipalities at Eskom's Megaflex rates that are not sustainable. The second condition is that the Municipality cannot enter into a long term power purchase agreement with an IPP without approval from National Treasury. The maximum term is three years. This condition is not good for investors who need long-term Power Purchase Agreements (PPAs).

Another problem with the MFMA is that it does not allow a free electricity market and encourages a captive market. Any customer who is in a Municipal area has to be supplied with electricity by the Municipality and cannot be supplied by any other person without the consent of the Municipality. Because Municipalities generate most of their revenue from electricity sales, they do not readily allow IPPs to sell power directly to their customers. In contrast, IPPs in Europe may have bilateral arrangements. Furthermore, there is an opportunity to sell their power to regional wholesale electricity markets, enabling cross boarder trading of electricity. Because there are no regional wholesale electricity markets in South Africa and its neighbouring countries, IPPs in South Africa cannot sell power to neighbouring countries despite that there is demand for power in these neighbouring countries (Namibia, Botswana and Zimbabwe).

4.1.2 Grid access

Grid access is another major barrier to the development of renewable energy in South Africa. Unlike the European electricity market which is liberalized, in South Africa, Eskom still has a monopoly in the electricity supply industry. It provides more than 90% of generation capacity in the country and is the sole grid operator. The IPPs therefore have to rely on Eskom for grid access. If Eskom's network needs to be upgraded to accommodate the IPPs, both the deep and shallow costs are normally charged to the IPP's account. Furthermore, Eskom does not guarantee a reasonable (say above 95% per year) availability of the grid to the IPP. If an IPP insists on this, Eskom charges connection costs for n-1[3] reliability criteria, which makes most projects unviable. In most cases, where Eskom would quote for the erection of just one transmission line, it would now quote for two lines. To mitigate this, the South African Government drafted the Independent System and Market Operator (ISMO) bill which will create an Independent System and Market Operator that will be responsible for buying electricity from Eskom and IPPs as well as operating the grid. Currently, this bill is still in parliament but once approved, it will go a long way in reducing the risk associated with grid access and unfair competition with Eskom.

In the absence of the ISMO, NERSA formulated the *Regulatory Rules on Network Charges for Third Party Transportation of Energy* in March 2013 [17] to make grid access easier. These rules aim to promote non-discriminatory access to the grid and ensuring transparency and cost reflectivity in setting network charges.

---

[3] *The most reliable design which provides for redundancy of equipment. If it is a transmission line, two lines are built and each line will have the capability of carrying the full load whilst the other line is out of service.*

4.1.3 Tariffs

The third barrier and maybe the most important one is the low electricity tariffs charged in South Africa. Eskom has been charging low tariffs because it had over-capacity until 2008 when it started practising load shedding. Eskom's electricity price as at 31 March 2013 was R0.63/kWh [18, 19], which is still low. Eskom has been trying to have cost reflective tariffs since 2010 when it applied for an average tariff increment of 35% per year for the three years of Multi-Year Price Determination 2 (MYPD2). However, the Energy Regulator granted only 24.8% for 2010/11, 25.8% for 2011/12 and 25.9% for the 2012/13 financial year. In 2012, the 25.9% increase for the 2012/13 financial year was revised downwards to 16%, partly because government reinvested its dividend into Eskom to shield the industry from steep electricity increases and partly because the REFIT programme that had been budgeted for did not materialize [20]. In 2013, Eskom applied for an average tariff increase of 16% for the next five years (2013-2018). Eskom argued that these increments will enable Eskom to move to a cost reflective tariff by 2018. However, NERSA granted Eskom an average increase of 8% for the next 5 years. Figure 8 below shows the price path of electricity in South Africa from 2008 up to 2018 (figures from 2013/14 are based on approved tariff increases).

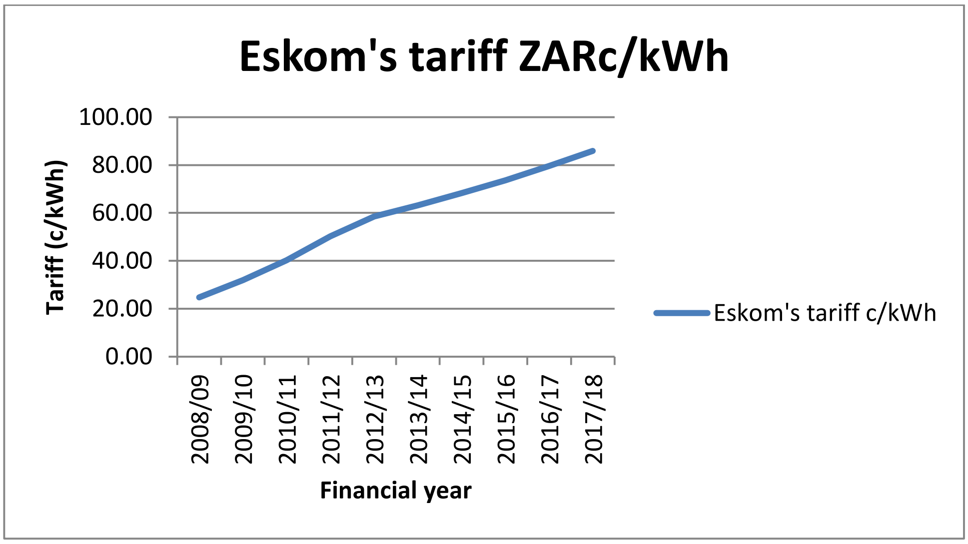


Figure 8: Electricity price path in South Africa[4]

[4] Calculated by author from information in Eskom's 2012/13 annual report

Although the graph shows a constant increase, the electricity charged in South Africa is far from being cost reflective. In Germany and Denmark, the domestic retail electricity tariffs (inclusive of taxes and levies) are high at 27c€/kWh (R4.05/kWh) and 30€c/kWh (R4.5/kWh)[5] respectively [21]. This makes it easier for wind energy to compete. It should be noted however, that wind energy is also cited as the reason for high tariffs in Germany and Denmark since the subsidies for wind energy come from taxes imposed on electricity consumers.

4.1.4 Societal acceptance

Environmentalists are opposed to the development of wind energy in some areas. This was raised in Port Elizabeth during NERSA's public hearings for generation licensing for Round 1 preferred bidders. The local community in Klein Rietfontein farm was opposed to the Metro Wind farm. Wind energy is also facing some resistance from the public because it is more expensive than coal-based generation. In a developing country where there is still poverty among the majority of the population, affordable electricity is a priority over environmental pollution caused by coal-fired power plants.

The scheme that will stimulate the development of renewable energy in South Africa has to be socially accepted. In Germany, social acceptance for wind projects was achieved by offering equity shareholding to farmers where projects were developed as well as giving them tax incentives [3]. In the UK, the solution might be offshore wind as there has been an increase in protests from the anti-wind groups for onshore wind [22].

4.1.5 Administrative barriers

The process of obtaining approvals and licences has been cited as one of the barriers to the introduction of renewable energy in South Africa [23]. There are too many parties involved in the granting of approvals for a project before it can be built. The processes of getting these approvals are unfortunately not streamlined. Parties involved in approvals are NERSA (generation licences), the Department of Environmental Affairs

[5] €/R = 15 as at 2013.

(Environmental Authorizations) and Department of Energy (approval of projects that are not in the Integrated Resource Plan). Before an IPP can apply for a generation licence to NERSA, it needs to get an Environmental Authorisation (EA) from the Department of Environmental Affairs amongst other requirements. The EA is expensive and time consuming. This will ultimately increase the project cost for the IPPs. This barrier may be eliminated by having one office co-ordinating the processing of approvals. This was successfully implemented in Denmark where the Danish Energy Agency (DEA) coordinates with other authorities to ensure that relevant permits are obtained before the project is implemented [24].

4.1.6 Financial

There are few financial companies that offer development grants in South Africa. This has prevented research and development into wind energy by IPPs. Securing equity partners and suitable commercial lenders has also been difficult because of the risks involved in renewable technologies. One solution to this problem is bringing in government participation into renewable energy. The government may provide guarantees to the banks. Alternatively, the government may provide a significant amount of capital in the form of equity, subordinate debt or mezzanine debt.

4.1.7 Skills

Shortage of technical skills for the manufacturing, installation and the operation of wind turbines has also been cited by developers as one of the barriers.

4.2 Support schemes considered by South Africa

The first renewable energy support scheme in South Africa was the Renewable Energy Subsidy that was being offered by the then Department of Minerals and Energy. When the Renewable Energy Finance Subsidy Office (REFSO) was opened in 2005, the subsidy was R250/kW and it rose to R1,000/kW in 2007 [25]. Tradable Renewable Energy Certificates (REC) were to provide additional revenue for the renewable energy projects.

This scheme was not very successful because the subsidies being offered were considered too low [23]. Only one wind farm, Darling wind farm, was developed under this scheme.

4.2.1 Overview of the REFIT scheme designed by NERSA

To accelerate the development of wind energy, the Government of South Africa introduced the REFIT scheme in 2009. The REFIT scheme was developed based on the 'Electricity Regulations on New Generation Capacity' of 5 August 2009. Under these regulations, NERSA was appointed to determine the REFIT tariffs and develop the selection criteria for IPPs that would participate in the REFIT procurement programme. The selected IPPs would enter into a 20-year PPA with Eskom. To implement this directive, NERSA developed the REFIT rates and published them on 26 March 2009. Only four technologies were chosen, namely wind, small hydro, landfill gas and Concentrated Solar Power (CSP). Table 1 below shows the technologies chosen and the determined REFIT rates.

Table 1: REFIT Tariffs - 2009 [26]

Technology	REFIT Rate (R/kWh)
Wind	1.25
Small Hydro	0.94
Landfill gas	0.90
Concentrated Solar	2.1

After the publication of these REFIT rates, there was concern that other deserving renewable energy technologies which can be commercially viable in South Africa were left out. Furthermore, CSP can be with storage or without storage and there was therefore a need to determine the REFIT rates for each technology separately. On 29 October 2009, NERSA published further REFIT rates for CSP with and without storage, biogas, biomass solid and photovoltaic technologies. Table 2 shows the REFIT rates as was determined by NERSA on 29 October 2009.

Table 2 REFIT Tariffs Phase II [27]

Technology	REFIT Rate (R/kWh)
CSP trough without storage	3.14
CSP trough with storage of 6 hrs per day	2.31
Large scale grid connected PV systems (≥1MW)	3.94
Biomass solid	1.18
Biogas	0.96

On 4 May 2011, the DoE published another set of 'Regulations on New generation Capacity'. These regulations effectively repealed those of 5 August 2009. The new regulations aimed to procure renewable energy using the bidding programme as opposed to REFIT. This was therefore an official end to the REFIT programme designed by NERSA.

4.2.2 Why REFIT was abandoned

Although the REFIT programme had been overwhelmingly accepted by developers, its legality was being questioned by the National Treasury. National Treasury argued that this programme was unlawful for three reasons. The first reason was that NERSA does not have the powers to pre-set tariffs before a generation licence is granted. The Electricity Regulation Act, 2006 (Act No. 4 of 2006) only empowers NERSA to set and approve prices, charges, rates and tariffs upon application by a licensee. In the REFIT programme, NERSA would have to determine the REFIT rates before the generation licence application was submitted. This would therefore be unlawful since it does not comply with the requirements of the Electricity Regulation Act.

The second reason cited by the National Treasury was that the REFIT does not comply with section 217(1) of the South African Constitution of 1996 which requires that organs of state must contract for goods or services in a fair, equitable, transparent, competitive and cost-effective manner. Since the price will be pre-determined in the REFIT programme, National Treasury argued that there is therefore no competitive bidding requirement on price as required by the constitution. It further argued that without competitive bidding on price, the REFIT programme was therefore not cost effective.

The third reason was that the REFIT programme did not comply with the Preferential Procurement Policy Framework Act 5, 2000.The Preferential Procurement Policy aims to give preference to the previously disadvantaged people during apartheid in a price-based bidding process. Once bids from the affected previously disadvantaged people achieve the minimum scores on functionality of the product, they must then be further evaluated based on the preference point system based on the price as prescribed by the Regulations. Since the REFIT programme has the same price for all IPPs, this framework will not be applicable.

After these issues were raised, NERSA sought legal opinion on the correctness of the three issues raised above. The opinion given[6] on the legality of pre-setting tariffs was that it is indeed unlawful and does not fulfil the requirements of Section 7, 14 and 15 of the Electricity Regulation Act.

On the compliance with the constitution on competitiveness and cost effectiveness of the REFIT, it can be argued that the REFIT is still competitive because IPPs would bid on the quality of the projects and not on price, thereby bringing in value for money. Moreover, Treasury Regulation 16A provides for exemption from this requirement if it is not practically possible to invite competitive bids. One reason that may be cited for requesting exemption is that the Government's White Paper on Renewable Energy is clear that the government intends to attract international investors to invest in renewable energy projects. The international investors would therefore be more comfortable with the REFIT as it had been successfully implemented in Europe by Germany, Denmark and Spain among other countries.

On the compliance of the REFIT programme with the Preferential Procurement Policy, the given opinion was that it indeed does not comply. The REFIT's Black Economic Score Card designed by NERSA in its REFIT selection criteria gives some preferential treatment to the previously disadvantaged but it is not based on a price point system as required by the law. However, there is provision for the Minister of Finance to exempt the procurer from this requirement if the likely tenders are international suppliers or if it

[6] From personal communication with NERSA's Legal Advisory Services Department.

is in the public interest. It can therefore be argued that the likely tenderers are the international suppliers. In the White Paper on Renewable Energy, the Government of South Africa has already decided that financial support for renewable energy has to come from a combination of South African and international sources [4].

Having concluded that the REFIT is illegal because it does not comply with the Electricity Regulation Act and the Preferential Procurement Policy Act, the question will be why was this not identified at the beginning before wasting time and money? The only logical answer is that the three government entities, namely the DoE, National Treasury and NERSA were not coordinating with each other and there might have been consolidation of power as well. Had National Treasury been consulted from the beginning, the shortcomings of the REFIT programme would have been raised earlier and solutions sought.

4.2.3 Overview of the bidding scheme designed by the DoE

The main players in South Africa's bidding procurement programme are the DoE, National Treasury, NERSA and Eskom. The DoE is responsible for undertaking the IPP procurement programme, from preparation of the bid proposal documents, requesting proposals, evaluation of proposals as well as selecting the preferred bidders. The DoE also acts as a government guarantor in case the buyer fails to fulfil its commercial obligation. Because money in government is controlled by the National Treasury, the National Treasury is effectively the guarantor. The National Treasury will therefore oversee the procurement process to ensure compliance with the Public Finance Management Act (PFMA). NERSA is responsible for consideration of generation licence applications from preferred bidders in accordance with the Electricity Regulation Act, 2006 (Act No. 4 of 2006). NERSA is also required to regulate tariffs and prices for the IPPs at licensing stage.

The selection criteria for successful bids requires that the bid price be equal to or below a certain cap as set by the DoE. For wind technology, this price cap is R1,150/MWh. The evaluation of bids will be done in two stages. The first stage is the qualification stage where the bids are evaluated for functionality and legal compliance. The second stage is the evaluation stage for ranking the bids based on price. The evaluation is based on 70% price and 30% economic development. The DBSA will be providing funding packages targeted at previously disadvantaged people who are minority equity shareholders.

The DoE requires all bidders to provide Single Bid Guarantees of R100,000/MW of the name plate capacity of each proposed facility to ensure that only serious bidders participate in this programme. If selected as a preferred bidder, the bidder will be required to submit Preferred Bidder guarantee of R200,000/MW of the nameplate rating.

To avoid grid congestion the DoE set the installed capacity of 140 MW for a single grid connection point for wind technology.

One of the disadvantage of a bidding programme in general, let alone a programme that gives 70% on price, is that bidders might opt for cheap technology so as to bring down the project costs. This risk was mitigated by the DoE by requiring that all wind turbines must be certified to IEC61400.

Bidders are also required to provide energy resource certainty by an independent reviewer as well as generation yield assessment report by an independent energy yield assessor. This condition will reduce risks of overstating wind resource. Risks of overstating wind resources is high in a bidding process as IPPs just want to be selected as preferred bidders but will under deliver during the project lifespan.

4.3 Concluding remarks

The development of grid-connected wind farms in South Africa has been slow despite the government's formulation of the White Paper on the Renewable Energy Policy in 2003. As at 2012, only three grid-connected wind farms were operating in South Africa with a total capacity of 10.16 MW. The slow pace of development is largely attributed to the electricity market structure which is captive, the low tariffs being charged by Eskom which makes power from IPPs uncompetitive and problems with grid access.

The REFIT was a good instrument to stimulate renewable energy and would have eliminated all the identified barriers. However, it was not legally sound as it did not comply with the Electricity Regulation Act and the Preferential Procurement Policy Framework Act. REFIT was therefore abandoned in favour of REBID. The REBID designed by DoE seems to address all the short-comings of UK’s auction scheme that failed. The inclusion of bid guarantee deposits, penalties for non-delivery of projects, certification of technologies and possession of permits before bidding will ensure that projects are delivered on time.

Before evaluating the economics of wind generation under REBID, we will identify the parameters that determine wind economics in general and try to relate them to South Africa in the REBID environment.

5 FACTORS THAT DETERMINE THE ECONOMICS OF WIND GENERATION

The five main parameters that govern wind power economics are:

- Electricity production / wind resources;
- Investment cost / capital cost of the wind farm;
- Finance cost / discount rate;
- Lifetime of turbines/ wind farm; and
- Operation and maintenance costs [28].

Each of these five parameters and how they affect the economics of wind energy in general will be discussed in the following section. Each parameter will be quantified for South African conditions and will be compared with those in European countries where wind energy was successfully implemented. A conclusion will then be made of that parameter’s contribution to economics of wind energy.

5.1 Electricity production - Wind resources

The commercial end-product of a wind turbine is the electricity produced. It has been shown in equation (1) that the electricity produced depends on the wind resources available. The economics of wind generation is therefore largely dependent on the amount of wind resources available. Knowing the available wind resources in any country at each site is therefore key for government authorities, utility planners, investors (owners and bankers) and consultants. Government authorities need to know wind resources available in the country to design energy policy as well as the best renewable energy support schemes/incentives for investments in wind energy and to ensure sustainability of those projects. The utility planners would use the information for long-term power system planning and investments in the grid. The investors, owners and bankers would need this information to identify locations that have the best wind resources so as to maximize the returns and accurately calculate the project risks. The consultants would use the wind resources data to choose the best suited wind turbine and design of a wind farm layout that will maximize the utilization of wind resources available at that particular site. The development of a wind database and wind atlas is therefore very crucial for any country that is serious about wind energy generation

5.1.1 Evaluation of wind resources in South Africa.

The wind atlas is a means of representing wind resource data on national or regional scales. In South Africa, the development of a wind atlas began in 1995 by Professor Roseanne Diab. She established that South Africa has very good wind resources (wind speeds of greater than 6 m/s) along the coastal areas. In 2001, Eskom and CSIR also did some studies on wind resources in South Africa. Dr Kilian Hagemann did further research on wind resources and he discovered that apart from good wind resources in the coastal areas, South Africa also has some good wind resources in the Northern, Western and Eastern Cape provinces. He concluded that South Africa has wind resources that are comparable to some of the windiest areas in the world. Figure 9 and 10 shows the wind atlas maps produced by Diab and Hagemann [29, 30].

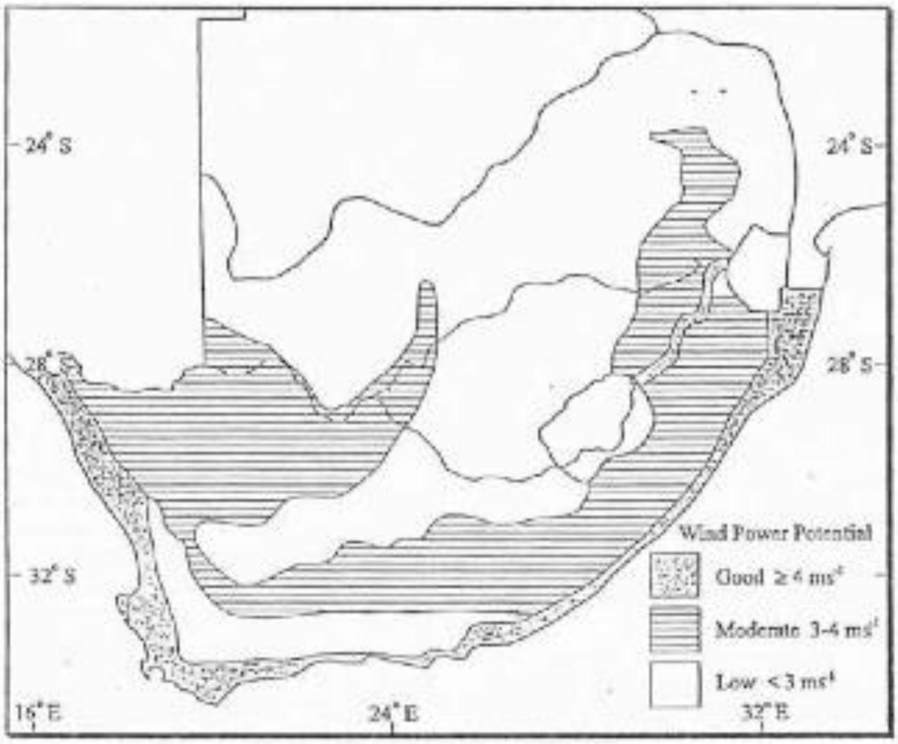


Figure 9: Diab's wind atlas map [29]

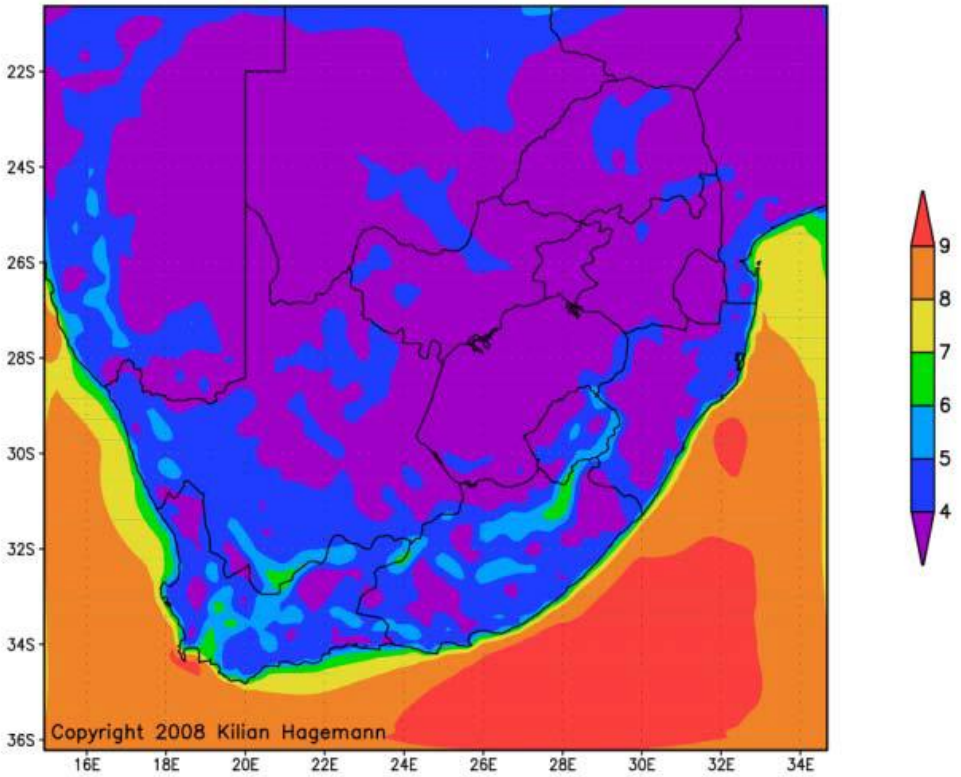


Figure 10: Hagemann's wind atlas map (bottom) [29]

According to the SANERI report of March 2012, the shortcoming of the Diab and Hagemmann's studies was that the data used was based on 10 m height measurements taken from weather stations. It has been shown in equations (1) and (2) that wind resources are a function of height above the ground. Since commercial wind turbines have hub heights of 60-120 m, it is important to use measurements taken at or near the hub height of the proposed wind turbine. The wind speed measured by instruments in weather stations is not the same as the wind speed at turbine hub height because wind blowing close to the ground is slowed down by the earth's surface, buildings and trees.

In 2009, the Department of Minerals and Energy initiated the Wind Atlas for South Africa (WASA) project. The project's objective was to provide a wind atlas for South Africa which will be used by the public to identify potential sites for on-grid and off-grid wind farms in South Africa. This project is expected to be concluded in 2014. In this study, ten 60 m height anemometry masts were installed in the Western Cape, parts of the Eastern Cape and parts of the Northern Cape provinces to measure the wind speed and direction. The wind speed is measured by anemometers installed at different heights of the mast whilst wind direction is measured by one or two wind vanes mounted on the mast. The sites for the 10 masts were carefully selected to represent the different types of terrain and climatology. Figure 11 shows the location of the wind masts used [31, 32].

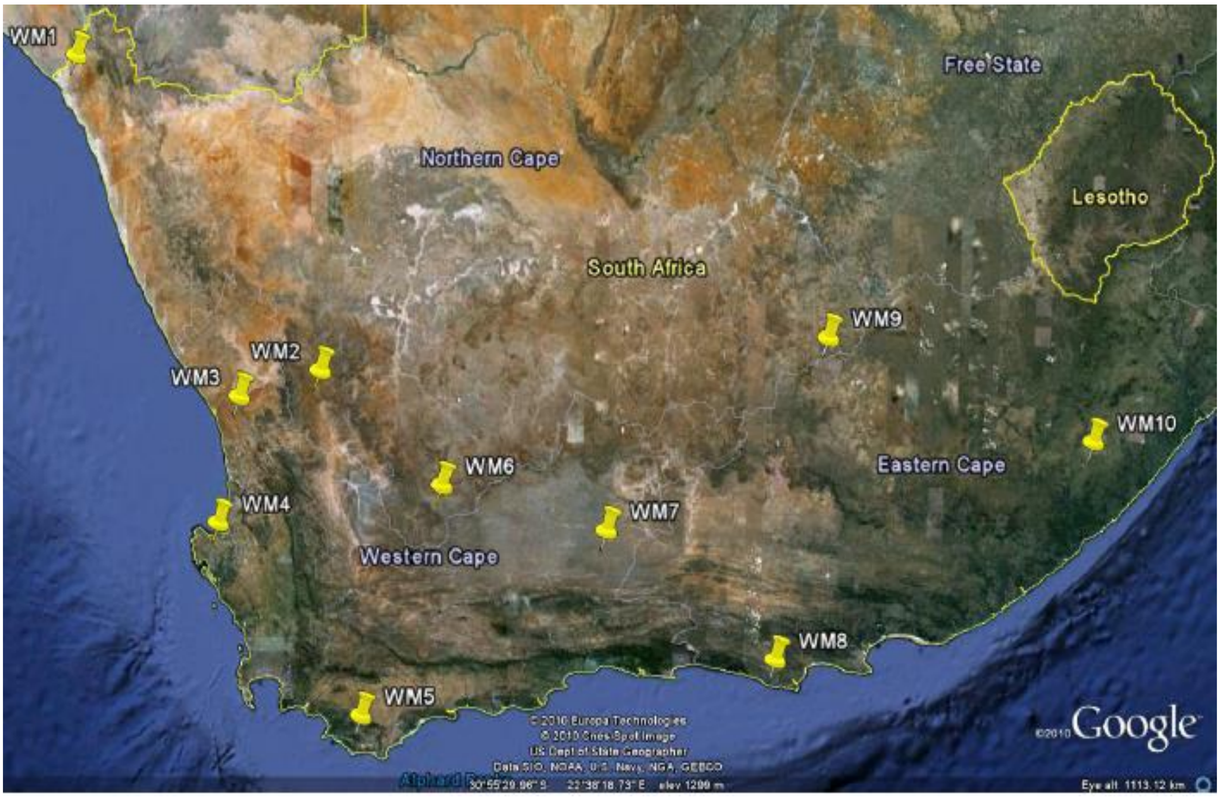


Figure 11: Location of wind mast [31]

Using data collected from the masts on Figure 11, WASA produced South Africa's first large scale high resolution wind resource map available to the public, shown below as Figure 12.

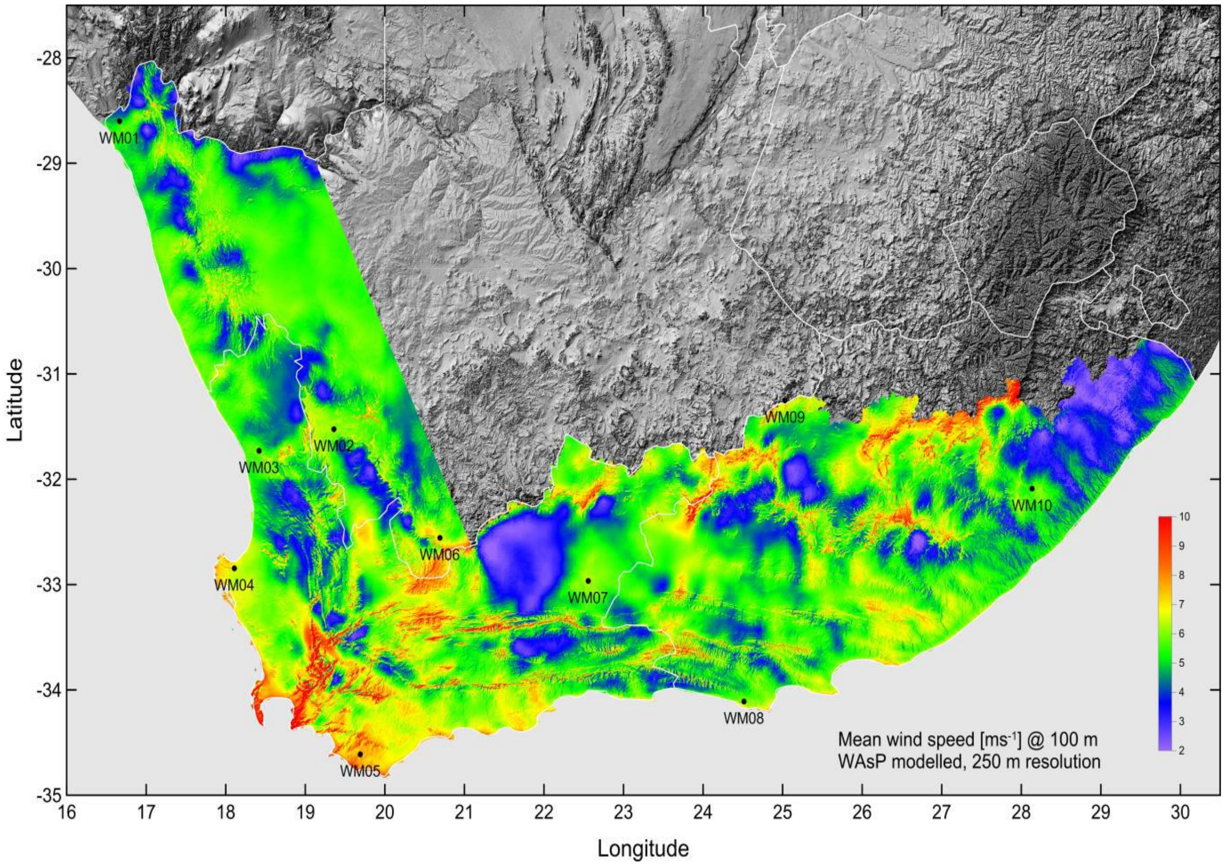
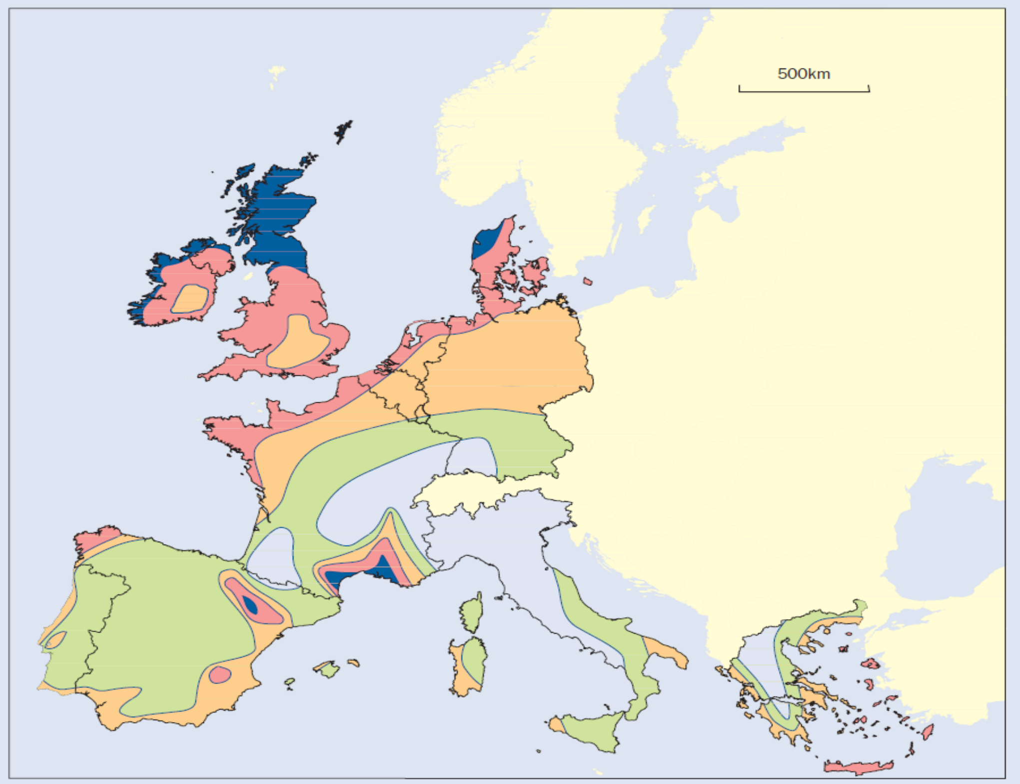


Figure 12: Large scale high resolution wind resource map of South Africa [33]

This map shows that there are even better wind speeds (greater than 6 m/s) in the coastal areas as well as some inland areas in the Western, Eastern and Northern Cape provinces than was discovered by Diab and Hagemann in their studies. These wind resources exceed those in some European countries where grid-tied wind farms were successfully installed. Figure 13 below shows the European wind atlas for comparison purposes.



Wind resources at 50 metres above ground level for five different topographic conditions										
	Sheltered terrain		Open terrain		At a sea coast		Open sea		Hills and ridges	
	ms^{-1}	Wm^{-2}	ms^{-1}	Wm^{-2}	ms^{-1}	Wm^{-2}	ms^{-1}	Wm^{-2}	ms^{-1}	Wm^{-2}
	>6.0	>250	>7.5	>500	>8.5	>700	>9.0	>800	>11.5	>1800
	5.0–6.0	150–250	6.5–7.5	300–500	7.0–8.5	400–700	8.0–9.0	600–800	10.0–11.5	1200–1800
	4.5–5.0	100–150	5.5–6.5	200–300	6.0–7.0	250–400	7.0–8.0	400–600	8.5–10.0	700–1200
	3.5–4.5	50–100	4.5–5.5	100–200	5.0–6.0	150–250	5.5–7.0	200–400	7.0–8.5	400–700
	<3.5	<50	<4.5	<100	<5.0	<150	<5.5	<200	<7.0	<400

Figure 13: European wind Atlas [38]

5.2 Capital cost/ Investment cost

Besides the wind resources, the second factor that determines the economics of wind energy is the capital cost. The capital cost of a wind farm is made up of the wind turbine cost, the distribution or the grid connection cost, the owner’s development cost, the cost for constructing balance of plant and Engineering, Procurement and Construction (EPC) services. Figure 14 below shows the cost share of each component in developed countries.

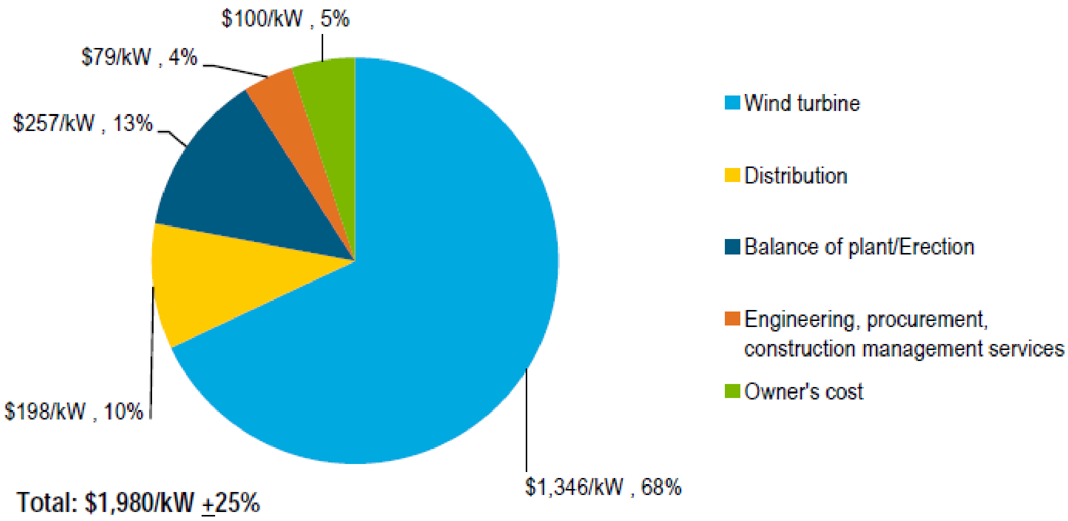
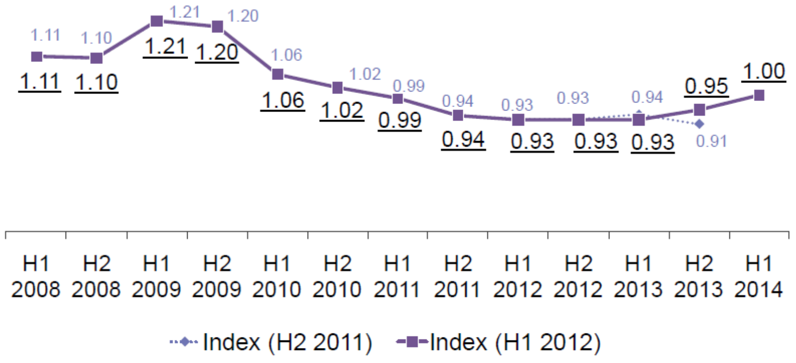


Figure 14: Capital cost of an onshore wind farm [35]

The turbine cost accounts for 68% of the total cost. This explains why several countries targeted local manufacturing of turbines as a condition of getting the support for developing wind farms. China required developers to use turbines made up of 70% locally manufactured materials [16]. USA required developers to use locally manufactured wind turbines in order to access the Production Tax Credit. This helped GE wind turbines to be installed more than any other wind turbine in the world in 2012, snatching the number one spot from Vestas [36]. Spain also required developers to use locally manufactured turbines in order to be considered for the support schemes [3].

5.2.1 Prices of wind turbines

Prices of wind turbines in Europe increased sharply in 2009 from around €1.11m/MW in 2008 to €1.12m/MW in 2009. This increase is attributed to increases in the price of steel, a major component in turbine manufacturing material. The turbine prices then decreased steadily to €0.93m/MW in the first half of 2013. However, the wind turbine price is expected to increase slightly to €1m/MW in 2014. This increase is attributed to upgrade of older turbines as developers try to take advantage of technological advancement over the last few years. Newer turbines are now taller, larger and more efficient, which would maximise utilisation of the available wind resources [14]. In South Africa, the Darling Wind Farm is considering upgrading the wind turbines to new models which are more efficient. Figure 15 below shows the trend of wind turbine costs in the past six years and projections for 2014.



Source: Bloomberg New Energy Finance. Note: "H1 2011" indicates where prices were estimated to be the last time Bloomberg New Energy Finance conducted its survey of buyers and sellers of turbines in the first half of 2011. Contract prices include turbine plus towers and transport to site, and they exclude VAT. Asian turbine contracts have been excluded from the analysis as they have much lower pricing.

Figure 15: Wind turbine prices by date of delivery (million Euro/MW) [14]

Since South Africa has no commercial turbine manufacturers, the preferred bidders are most likely to source the turbines from European countries. The turbine prices are expected to be slightly higher than shown on Figure 15 because of higher transport cost. There is also higher probability of preferred bidders opting for Indian and Chinese turbines which are cheaper [14] than European manufactured turbines.

5.2.2 Grid connection cost

The grid connection cost includes the cost of connecting to the local distribution or transmission lines including the necessary substation upgrades to accommodate additional capacity. It is normal practice to include only shallow costs (cost for connecting the wind farm to the nearest grid connection point), and not deep cost (cost of strengthening the transmission network). In Germany, the renewable energy IPPs are guaranteed grid access and the connection cost does not include grid reinforcement [37]. It is desirable therefore, to site the wind farm closer to the grid to reduce the connection cost. However, a trade-off has to be made between the site accessibility, wind resource availability and grid accessibility. Of the three factors, wind resources far outweigh the other factors in determining the economics of wind generation. Cost of grid connection and site preparation is only once-off whilst the wind resources influences the viability of the project for the rest of project lifespan. The grid connection cost accounts for 9-14%

of the total investment cost of a wind project [35]. Without project specific information, 10% is normally used in financial models.

In Europe, electrification is almost 100%. The wind farms therefore have better access to the grid and grid connection costs are lower. This is different in South Africa where some areas in the Western and Eastern Cape provinces, where wind resources are abundant, are not electrified. The grid connection costs are therefore expected to be higher as compared to costs in European countries.

5.2.3 Cost of balance of plant

Cost of balance of plant is related to cost of civil works, electrical and control systems of the plant. Civil works include site preparation, road access to site (very important for the transportation of the turbines by heavy vehicles) and turbine foundations. Electrical works include transformer installations, line erections and control systems.

In Europe, this accounts for 13% of the total project cost as shown in Figure 14. In South Africa, all materials needed for civil, electrical and control works are available locally at competitive prices. The cost of electrical works is therefore expected to be comparable with costs in Europe, if not lower due to cheap labour in South Africa than Europe.

5.2.4 Project development costs

This cost includes cost of feasibility studies to ascertain wind resources, permits such as environmental authorisations and land use rights, as well as project consultancy fees. The cost of feasibility studies can be reduced if there is a readily available wind resource data to the public for use. This is the major reason for the development of the Wind Atlas of South Africa (WASA) project discussed above.

The process of obtaining permits was cited above as one of the barriers into renewable energy. Environmental Authorisation (EA) in South Africa may take more than a year and the process involves environmental impact assessment which is costly. The development costs in Europe are estimated to be 5% of the project cost as shown on

Figure 14. In South Africa, no data is available for the development cost of wind projects so this European benchmark will be used for the South African environment.

5.3 Finance costs / Discount rate

The cost of debt and equity has a major effect of the total cost of the project and subsequently on the economic feasibility of the project. The financial market of each country influences the interest rates offered by the banks and the preferred return on equity required by investors. Factors that influence the interest rates on debt and required return on equity are availability of capital in a particular country, government policies on cost of capital, risk perceptions by financial institutions on a particular class of projects such as wind technology, inflation rates and demand for credit. In developing countries, the finance industry is normally less competitive as compared to developed countries and the interest rates are therefore normally high. Because of the perceived high risk of the investments in developing countries, investors normally demand high returns on investments. Apart from the macro-economic parameters, the technological risks increase the cost of capital. Technologies with a proven track record and minimum operational risk profile are preferred by financiers and would be charged less interest. According to [38] onshore wind technology is considered to be the most proven technology amongst the renewable energy technologies and has therefore a relatively low risk from a project finance perspective. It is expected therefore that international financiers who have experience of financing wind energy projects in European countries would be willing to invest in South Africa without worrying about technological risks. This will force the local financial banks, which have little experience in financing grid connected wind farms, to compete as well, pushing down the financial cost.

South Africa, although it is a developing country, has a stable inflation rate (which has been less than 6% for the past three years), sound financial institutions and a sound legal system which investors may use to seek recourse in courts of law. These three factors are likely to influence a low cost of capital for wind energy projects in South Africa.

Apart from the local commercial banks, the Development Bank of Southern Africa (DBSA) and the Industrial Development Corporation (IDC) are strong enough to participate in the renewable energy projects if there is a conducive environment. These two development banks are expected to offer finance for wind projects at more favourable rates than the commercial banks. The effect of a strong financial market on development of renewable energy was shown in Germany by the German Bank for Reconstruction and Development (KfW), a state owned bank. It stimulated renewable energy by offering cheap loans for up to 75% of the project cost at below market interest rates with favourable long loan terms. The loan would come with a redemption-free period of up to 3 years in some instances [44]. In 2013, KfW bank charged 4.39% interest rate for the highest credit rating class for wind developers [54]. Without project specific information, the discount rate used to evaluate the economics of wind energy in developed countries ranges from 5% - 10% [6]. In South Africa, the swap rate alone is 8.5% as at 2011. The discount rate is therefore expected to be more than 10%.

5.4 Operation and Maintenance (O&M) Cost

Another parameter that determines the economics of a wind farm is the operation and maintenance cost. This is the cost incurred during the day to day running of the wind farm. Most of the costs are fixed - they do not vary with the amount of electricity produced. Fuel cost, which is the major contributor to variable costs in power plants, is free. It is therefore standard practice to look at fixed costs when determining the O&M costs of a wind farm. The O&M cost components are:

- insurance cost;
- regular or scheduled maintenance costs;
- repair costs;
- spare parts;
- land lease costs; and
- administration

One way of reducing these costs is to secure long term contracts for insurance, land lease and maintenance. This will only leave the developer to deal with the cost of spares and labour cost for major repairs not covered in the operation and maintenance contract. Like any other machine, the repair cost and hence the O&M costs, increase as the turbine gets older.

Even in Europe, it is difficult to accurately estimate the O&M costs for wind farms because the wind industry is still young and few wind turbines have reached the end of their life span [6]. Furthermore, the few wind turbines that are reaching the end of their lifespan used old technology which requires more maintenance.

The O&M costs vary from country to country due to different labour costs among other factors. However, the fact that operation and maintenance of wind farms can be done through the internet will ensure that the O&M costs in South Africa are similar to those in Europe.

5.5 Lifetime of turbines

The more the turbines remain in service, the more electricity they will produce over their lifespan. The economics of wind energy is therefore also dependent on the turbine lifespan. Turbine lifespan is determined by the manufacturer. Most of the commercial turbines employed today have a 20 year lifespan [6].

5.6 Concluding remarks

Factors that determine the economics of wind turbines have been identified as the wind resources, the capital cost, the finance cost, the operation and maintenance cost and the lifetime of the turbine. Of these parameters, the wind resources have the greatest influence. The recently produced South African Wind Atlas shows that South Africa has very good wind resources (more than 6m/s) in the coastal and inland areas of the Eastern Cape, Western Cape and Northern Cape provinces. These wind resources are comparable to wind resources in Europe and can sustain wind generation in South Africa.

The only factor that will make wind energy in South Africa more expensive than in Europe is the discount rate. The cost of capital in South Africa is higher due to weaker financial markets than in Europe. However, South Africa has enough financial institutions to support renewable energy, albeit at a higher cost.

6 EVALUATION OF REBID SCHEME

Having identified the barriers to the development of renewable energy in general and wind energy in particular, it is crucial to evaluate the success or failure of the bidding scheme launched by the DoE after the abandonment of the REFIT scheme. In order to do this, an analysis has to be done on the environment in which the bidding scheme has to operate. This analysis will focus on the political situation (rule of law), renewable energy policy and regulations thereof as well as the regulatory environment. Once this analysis is done and a conclusion made, an analysis of the results from the bidding scheme is done using the first, second and third bidding rounds concluded by the DoE.

6.1 Rule of Law, Renewable Energy Policy and Regulatory Environment

Foreign investors are attracted to invest in countries where the rule of law is respected. This will ensure enforceability of contracts signed before an investment is made. This is particularly more important where such contracts are between private companies and an organ of state or parastatal. Without a strong rule of law, it is difficult to enforce claims or judgment against a parastatal. Eskom, the buyer of electricity in the renewable energy procurement programme, is a state-owned electricity service provider in South Africa. The rule of law will therefore be a critical factor for foreign investors. Fortunately, South Africa has a strong rule of law and contracts are enforceable. Foreign investors are therefore keen to invest in South Africa. This was evidenced by a large turnout of foreign investors during the DoE's bidding briefing notes held in Johannesburg.

Apart from the rule of law, investors want a clear government policy on renewable energy in order to make long-term commitments. The White Paper on the Renewable Energy Policy discussed in the introduction has been the major driving force of renewable energy in South Africa. However, lack of legal framework for IPPs was one of the barriers in the development of renewable energy. In South Africa, Eskom is a monopoly in the electricity sector and is the sole owner of the national grid. Grid access for IPPs is therefore very difficult without a proper legal framework. The DoE recognized this and designed the 'Regulations on New Generation Capacity' of 4 May 2011 [39]. These regulations clearly spell out that the Minister can determine who will establish new generation capacity, whether it will be Eskom, another organ of state or an IPP. If this capacity is going to be established by an IPP, the Minister will also determine the procurer and the buyer. These regulations give the Minister the powers to determine that the renewable energy will be procured by the DoE and Eskom will be the single buyer. Apart from providing a sound legal framework for the development of renewable energy in South Africa, these regulations also ensure grid access for IPPs since Eskom, the grid owner, is the sole buyer of all renewable energy. In a way, these regulations and Germany's Renewable Energy Sources Act (EEG) that was implemented in 2000 are addressing the same barriers to renewable energy - that is guaranteed access to the grid and a pre-determined renewable energy tariff. Under the EEG, renewable energy is given priority for grid connection, grid access and power dispatch.

Another important policy that will support the development of renewable energy going forward is the Carbon Tax policy planned to be introduced in 2015. The overall objective of this policy is to reduce greenhouse gas emissions and facilitating the transition to a green economy. The National Treasury has since released a Carbon Tax Policy Paper on 2 May 2013 for public comment. Although the electricity sector will initially qualify for a tax free threshold of up to 70%, this policy will enable energy from renewable sources to be more competitive with coal-based generation [40].

6.2 Social acceptance and participation of all role players from an early stage

Failure of the REFIT programme was partly because of the exclusion of the National Treasury. In the REBID programme, all role players were involved from the beginning. These are the DoE, NERSA, National Treasury and Eskom. Eskom, as the sole buyer, was more involved in the drafting of the standard PPA. NERSA's licensing requirements were included in the bid documents. This helped all parties to accept the programme and by including each party's requirements in the bid documents, a situation whereby the preferred bidder is denied a generation licence or where the buyer refuses to sign the PPA was avoided.

6.3 Technology

One of the pitfalls of using a tendering process based on 70% price is that cheap technology may be dumped in the South African market. To prevent this, the DoE's selection criteria required the selected turbine technology to be IEC certified. The pie chart of Figure 16 shows that Vestas, a well-known and reliable Danish brand is dominating the South African market. It is also interesting to note that there are two turbine manufacturers from China, namely Snovel and United Power UP86. This shows that China has become an integral player in the wind energy market both on technology development and installed capacity. Both Snovel and United Power are in the top 10 rankings for installing the greatest wind capacity (MW) in 2012 [36, 41].

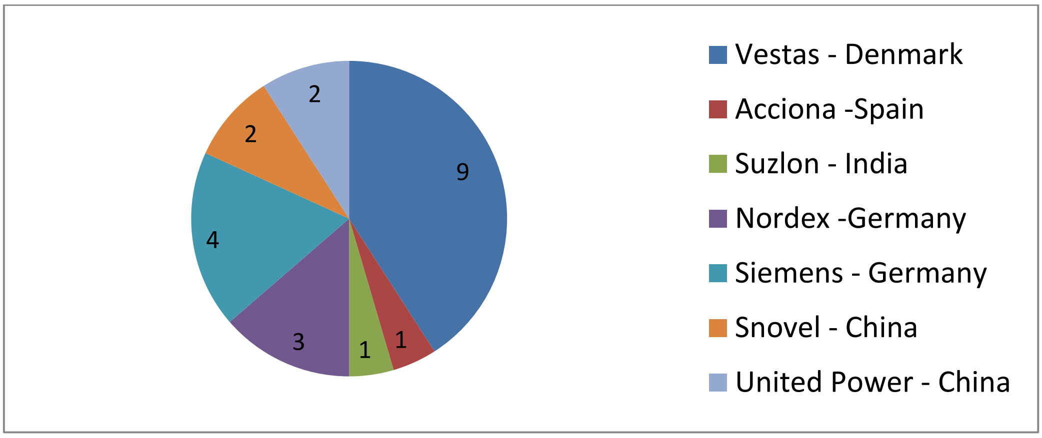


Figure 16: Pie Chart showing turbine market share in South Africa

This trend is consistent with global trends where Vestas has been the market leader on commissioned wind capacity since 2001 [36]. Vestas was only displaced from the number one spot in 2012 by General Electric of the United States of America by a slight margin. But unlike Vestas, more than 96% [41] of the General Electric wind turbines commissioned in 2012 were in the American market. This trend might not necessarily continue as the surge in the GE turbines installed is attributed to the American incentive schemes where all projects had to be grid connected prior to the 2012 year end in order to qualify for the expiring tax credit [41, 5]. Vestas is therefore likely to regain its market share. Figure17 below shows Bloomberg New Energy Finance's ranking of the top 10 wind turbine manufacturers by commissioned capacity in 2012.

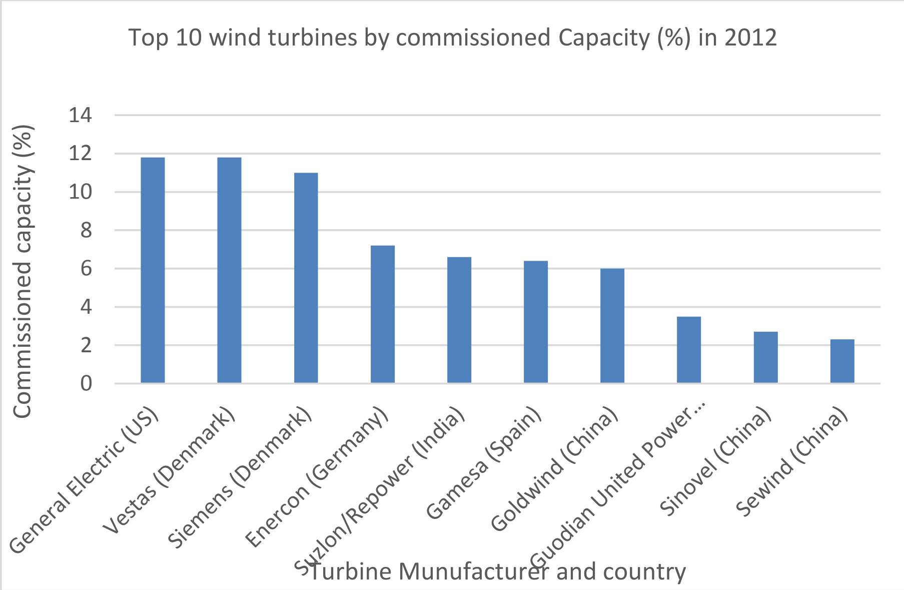


Figure 17: Top 10 wind turbines by commissioned capacity in 2012[7]

Acciona is not in the top 10 ranking by commissioned capacity in 2012 but it is ranked number 7 in the top 20 wind asset owners (cumulative capacity at year end 2012) in the world [41]. This clearly shows that the price based bidding process did not result in compromise on technology. Instead, well tried technologies with good track records dominated the South African market.

6.4 Wind resources (Sites chosen by IPPs)

Figure 18 below shows the location of the wind farms for the DoE procurement programme. Yellow icons represent eight IPPs from the first bidding round, red icons represent seven IPPs from the second phase and the green icons represent the seven IPPs from the third round. The chosen sites for these projects are mostly in the Eastern Cape and Western Cape during the first and second round but more wind farms were chosen in the Northern Cape for the third round, possibly as a result of more attractive sites being taken in the first and second rounds.

[7] Drawn by author from information in [41]

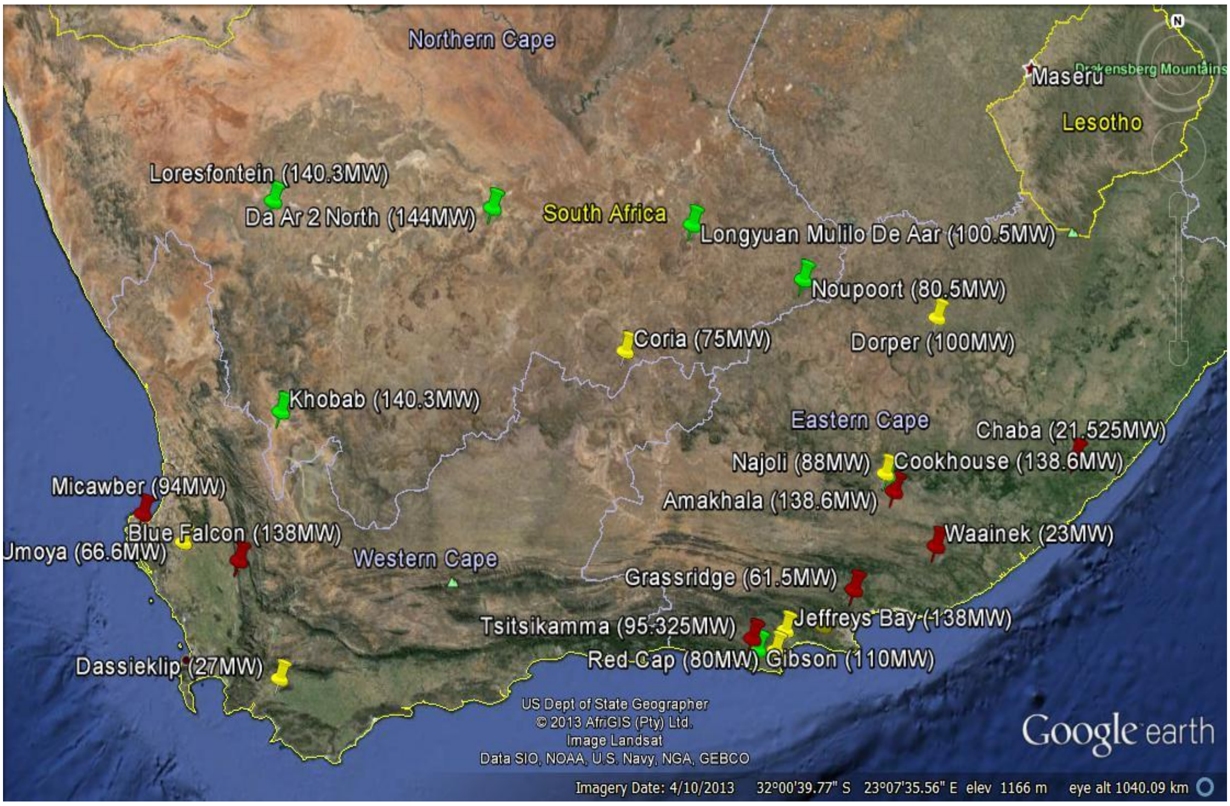


Figure 18: Distribution of wind farms

This pattern shows that development of wind farms is on high wind sites as identified in South Africa's wind resource map shown on Figure 11.

6.5 Capacity allocation and Tariffs under REBID

Figure 19 shows the capacity allocation during the three bidding rounds. It should be highlighted that in the first bidding round, there was no specific target allocation. The 1850 MW available was the total capacity available but to be procured over several bidding rounds depending on the bid price. In the second and third rounds, the available capacity was set at 650 MW and 654 MW respectively. The target capacity in the third phase was exceeded slightly. Figure 18 also shows that the REBID tariffs have decreased significantly from the first bidding round to the third bidding round. The decrease in the average tariff shows that the competitive bidding is actually helping South Africa to get value for money. This scenario was unlikely to be seen with the REFIT which shows slight increase in tariffs for the same period (2011 to 2013).The lower tariffs may also be attributed to investor confidence after the first procurement phase was held successfully.

All the policy uncertainties that had been brought by slow progress of REFIT and the eventual change from REFIT to REBID seemed to have now been forgotten.

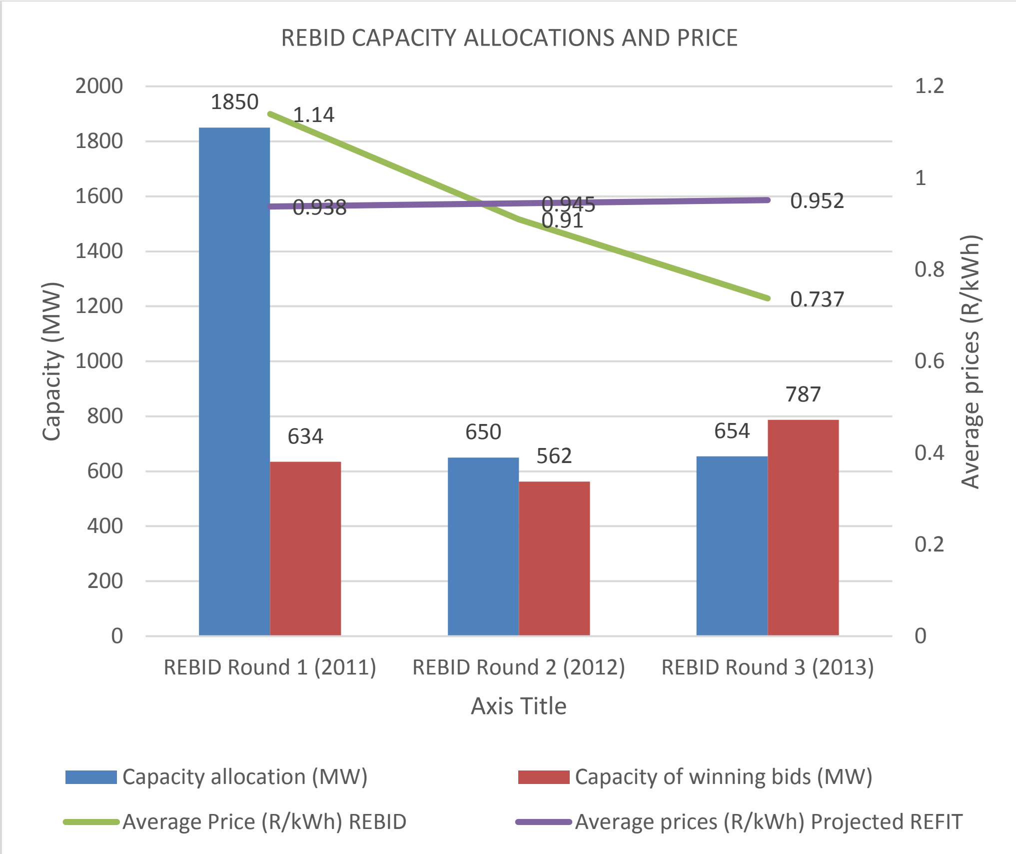


Figure 19: REBID capacity allocation and tariff comparison with REFIT

6.6 Capital investment cost

The average capital investment cost for the first phase projects is US$2,419/kW and for the second phase projects is US$2,509/kW[8]. This is on a high end as compared to investments costs in European countries (US$1,700-US$2,450/kW) for the same period [43]. This might be attributed to the higher cost of finance and higher transport cost of turbines from the manufacturers. From Figure 16 above, all wind turbine manufacturers that will supply wind turbines in South Africa are based in Europe and Asian countries and the turbines have to be shipped into the country. In the third bidding phase, the investment capital cost of wind projects was US$2,064/kWh. The decrease as compared

[8]Calculated by author using information from [42], 2011 prices

to second phase may be attributed to lower cost of capital as most of the third round preferred bidders are large international corporate companies with strong balance sheet.

South Africa proved that it has a strong financial market capable of supporting renewable energy. For the round three procurement programme, Absa provided finance to six projects [44] whilst Nedbank provided finance to seven projects [45]. Standard Bank also participated in this programme by providing finance for the first, second and third rounds. The state owned DBSA provided loans mostly to local entrepreneurs who partnered with the foreign investors. Apart from banks, some asset financial firms such as Futuregrowth Asset Management Company provided financing to renewable energy projects. Futuregrowth Asset Management Company provided funding to 23 of the 64 projects selected in the three rounds of the renewable energy procurement programme [46].

6.7 Operation and maintenance costs

Most developers contracted the turbine suppliers to do the operation and maintenance during the first few years of the projects with the condition of training the local workforce and eventually transferring the knowledge and skills after 5 - 10 years.

6.8 Grid connection

In South Africa, the grid is operated by Eskom. Generally any transmission system upgrade required to connect a wind farm is partly sponsored by the farm owner, sometimes in full. To make matters worse, most of the wind farms in South Africa are located in remote areas where there is ether no grid or weak grid that would require the substation and the transmission lines to be upgraded. Some are connected to the distribution networks owned by the Municipalities.

From the transmission loss point of view, the wind farms in South Africa will significantly reduce the transmission losses. The wind farms are strategically located in the Western and Eastern Cape areas, far away from the generation points in the Mpumalanga Province. Figure 20 below shows the location of the generation stations in the country in relation to the Western Cape Province. This Figure shows that most of the power stations are located in the Mpumalanga province. The Western Cape and the Eastern Cape provinces are fed from the Mpumalanga province through long 765 kV and 400 kV lines, which account for a lot of technical losses.

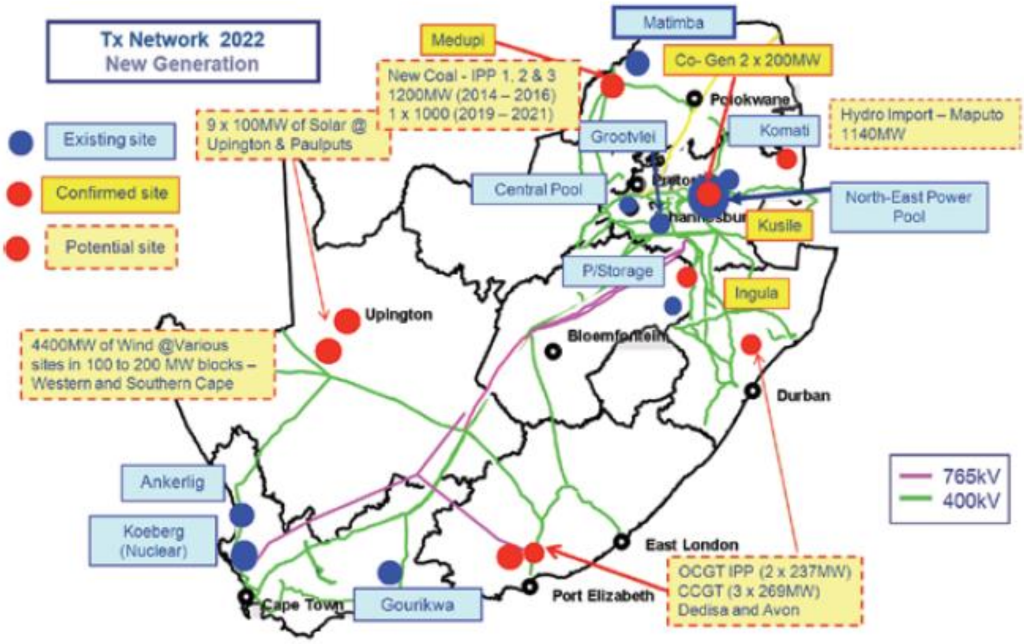


Figure 20: Eskom's existing and planned generation capacity [47]

Eskom currently plans to strengthen the power lines going to the Cape so as to reduce losses and improve the reliability. Any generation in the Cape would therefore reduce the investment cost of transmission lines required.

6.9 Concluding remarks

South Africa has a political stability which is unquestionable. There is rule of law where companies may seek recourse in the courts of law when they feel aggrieved by any party. In addition to the renewable energy policy (White Paper on Renewable Energy policy), that shows long term commitment to renewable energy, the South African government produced the Integrated Resource Plan (IRP 2010-2030) which shows long-term commitment to renewable energy in general and wind energy in particular. This will encourage international developers and investors to set up offices and invest in the development of renewable energy projects.

Although the bidding scheme was based on 70% price, the developers did not use cheap technology as was feared by many analysts. This might be attributed to the well-designed bidding documents which required turbine certification as a condition of technical evaluation.

Although the developers started the projects before the wind atlas was released to the public by the DoE, the sites chosen indicate that wind resources are good in the Western Cape, Eastern Cape and Northern Cape provinces, just as was discovered by Diab and Hagemann. This is also consistent with the wind atlas that was released by DoE for public use in 2013.

Just like the UK's bidding scheme of the 1990s, the tariffs went down from an average of R1.14/kWh in the first round to R0.656/kWh in the third round (using 2011 as base year), thanks to the competitive nature of the bidding. This was never going to happen under the REFIT scheme. At the time of conclusion of this report, the indications are that all projects will reach the scheduled CODs. In fact some projects will reach COD earlier than scheduled. All wind projects had reached financial close and construction had started on all sites[9]. This success may be attributed to the fact that the projects with permits (especially the environmental authorizations) were chosen. The imposition of penalties for COD delays and non-performance ensured that South Africa avoided pitfalls faced by the UK's bidding scheme. Bidders were therefore encouraged to honour the CODs and ensured performance of wind turbines by contacting reputable turbine suppliers and EPC contractors.

[9] Eskom's presentation to Parliament Portfolio Committee on Energy of 5 November 2013.

7 LEVELISED COST OF ELECTRICITY (LCOE) FOR WIND

LCOE is the ratio of the total cost of running the plant over its lifetime and the electricity produced over the life cycle of the plant, all brought to the present-day value. It is measured in unit currency per kWh or MWh. It measures the unit cost of electricity irrespective of technology or operating regime of the plant. This method can therefore be used to compare cost of energy from different technologies with different dispatch rules. The LCOE may also be interpreted as the 'break even' price of electricity required by investors for a specified return. This break-even price may be used as the FIT tariff in FIT schemes. Alternatively, it may be used to set the premium required by simply looking at the difference between the market price and the LCOE.

The five basic parameters that determine the LCOE are the installed capital cost, the operating cost, the discount rate, the lifespan of the project and the electricity produced. It is interesting to note that these same parameters also determine the economics of wind generation as discussed above. The LCOE may therefore be used to evaluate the economics of wind generation. It should be noted however, that this method does not account for other benefits such as job creation and reduction in greenhouse gas emissions.

Equation (8) shows how LCOE for wind can be calculated [49].

$$LCOE = \frac{I_o + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{M_{el}}{(1+i)^t}} \tag{8}$$

where,

I_o is the project capital or investment cost in US$/kWh

A_t is the annual operation total costs in year t (fixed and variable)

M_{et} is the annual electricity output in year t in kWh

i is the discount rate

n is the economic lifetime in years

t is the year of operation (1,2,….n)

Each of the parameters in equation (8) is associated with a set of assumptions. When calculating the LCOE, it is therefore important to do a sensitivity analysis by changing the assumptions and analysing the effect of that parameter on the LCOE. This will give a more holistic picture than relying on only a single number or calculation. The following sections will look at the assumptions made for calculation of LCOE for wind energy in South Africa in order to assess the economics of wind energy.

7.1.1 Capital cost

From the REBID programme, the capital cost ranged from R15,535/kW to R24,537/kW. An average will be used which is R20,899/kW (US$2,089.9/kW[10]) as the base case and extremes will be used to test sensitivity of the LCOE for this parameter. The construction period for a 100 MW wind farm is chosen to be two years, which is consistent with what was allowed for by the licensed preferred bidders and what is used by international benchmarks such as EIA [48]. NREL estimated that the cost of capital ranges from US$1,400/kW to US$2,900/kW with an average of US$2,090/kW.

7.1.2 Discount rate

The Weighted Average Cost of Capital (WACC) methodology is used to calculate the discount rate. The WACC depends on the volume of equity, cost of equity, volume of debt and cost of debt. Changing the capital structure (debt-equity ratios) therefore has an impact on WACC and ultimately on LCOE. Cost of debt is normally lower than cost of equity because banks have first priority of recovering their money if the project fails unlike investors. Equation (9) below gives the formula used to calculate the WACC in this project:

$$Real\ WACC\ after\ tax = W_e r_e + W_d (1 - T) r_d \tag{9}$$

where W_e is Weight of equity in percentage,
r_e is real return on equity after tax,
W_d is weight of debt in percentage,
r_d is nominal return on debt pre-tax,
T is corporate tax rate, which is 28% in South Africa.

[10] Assumed $/R =10 as at 2013.

It should be noted that since the cost of debt or interest is tax deductible, we therefore deduct the current corporate tax rate of the cost of debt.

The real return on equity after tax, $r_{e,}$ is determined by the shareholders' requirements depending on the macro-economic conditions in that country. In this project, we shall assume 17%, as was used by NERSA during calculation of REFIT (this was based on wide consultations done by NERSA). This is higher than what would be required in European countries because of a strong financial market and low inflation rates there than in South Africa.

The real return on debt after tax has to be calculated from the nominal return on debt after tax. Nominal return on debt is influenced by three parameters for renewable energy. These are the swap rate of the country where debt is sourced, the risk premium of the project and the hedging costs. In South Africa, the swap rate is 8.5% (2011 base year), the hedging cost is assumed to be 1% and the risk premium is 4%. This brings the nominal cost of debt to 13.8%. Since nominal return on debt is affected by inflation, we have to calculate the real return on debt, $r_{dr,}$ which takes rate of inflation, e, into consideration. Six percent inflation will be used in this project since it is South Africa's upper limit inflation target. It should be highlighted that NERSA had assumed the inflation rate of 8% in the REFIT calculations in 2009. In developed countries such as Germany, this can be as low as 2%. Real rate of return after tax is calculated using formula 10 below [50].

$$r_{dr} = [(1 + r_{dn})/(1 + e)] - 1 \qquad (10)$$

Since tax is a pass-through cost for investors, investors are more interested in the real WACC before tax. To calculate the real WACC before tax, the following formula is used [55].

$$Real\ WACC\ before\ tax = \frac{Real\ WACC\ after\ tax}{(1 - Tax\ rate)} \qquad (11)$$

The calculated real WACC before tax is the discount rate used to calculate the LCOE.

Table 3 below summarises the financial parameters and formulas used to calculate the real discount rate for our base case scenario.

Table 3: Financial parameters used to calculate discount rate for LCOE

	Unit	Symbol/Formulae	Value
Equity	%		30%
Debt	%		70%
20 year swap rate (2013)	%	A	8.50%
Risk premium	%	B	4%
Hedging costs	%	C	1%
Nominal cost of debt after tax		**Rdn=A+B+C**	**13.50%**
Real return on equity after tax		Rera	17%
South Africa's inflation target	%	E	6%
Tax rate	%	T	28%
Real return on debt after tax	%	Rdra=(1+Rdn)/(1+e)-1	7.08%
WACC real after tax	%	DRreala=Rdr.D.(1-T)+Rera.E	8.67%
WACC real before tax	%	DRrealb=DRreala/(1-T)	12.04%
LCOE real discount rate before tax	**%**		**12.04%**

By using real WACC, we get real LCOE which may be used as the PPA tariff in the first year. In order to understand the differences in the financial parameters in South Africa as compared to European countries, Table 4 below shows the financial parameters in Europe versus those used by the author.

Table 4: Financial parameters used to calculate LCOE in European countries

	Germany and Spain[11]	Used by Author[12]
Lifetime of project	20	20
Share of equity	30%	30%
Share of debt	70%	70%
Return on equity	9%	17%
Debt rate	4.5%	8.5%
Inflation	2%	6%
WACC real	3.8%	12.04%

[11] Adopted from [49] and [54]

[12] Calculated from table 7

7.1.3 Capacity Factor

The capacity factors from REBID will be used to calculate the LCOE. The average capacity factors range from 25% to 40% with an average of 35%. The average will be used as the base case whilst the extremes will be used to test the sensitivity of LCOE to this parameter.

7.1.4 Life cycle of the project

We shall use 20 years as the lifetime of the project which is in line with turbine manufacturer's warranties and the REBID PPA.

7.1.5 Annual Operation cost

The maintenance cost depends on the quality of the turbines used and their age. Maintenance costs increase as the turbine gets older. New models are also cheaper to maintain than old models because of technological improvements employed on new models. The value from international benchmarks is US$15/kW-US$35/kW with an average of US$22/kW (base case). These are the values that will also be used for this calculation since we do not have enough data for O&M costs for wind turbines in South Africa.

7.2 LCOE calculation methodologies

There are several methodologies used to calculate LCOE. However, these methodologies may be grouped into two main categories, the Discounted Cash Flow (DCF) analysis and the Recovery Factor analysis. In the DCF analysis, the project's annual net cash flows are discounted to a single net present value and the internal rate of return. The LCOE will then be revenue per kilowatt-hour that makes the net present value to be equal to zero [51]. The CREST[13] and System Advisor Model (SAM)[14] models use this methodology to calculate the LCOE and both models are available to the public.

The second method uses a single factor to convert capital investment costs to an annual

[13]Available at http://financere.nrel.gov/finance/content/CREST-model
[14]Available at https://sam.nrel.gov/content/downloads

figure that estimates tax benefits or obligations and repayments to all capital providers over the lifespan of the project. Capital Recovery Factor, Fixed Charge Rate and Economic Carrying Charge Rate (ECCR) all fall under this category. More description and formulas for calculating LCOE using these methodologies can be found in [51]. Gifford et al [57] recommends the use of Discounted Cash Flow analysis method in evaluating LCOE in the United States because of its ability to incorporate all available federal and state tax incentives that are the major incentives for the development of renewable energy in the United States. This method is not suitable in South Africa where there is a single tax system and no state tax or renewable energy tax incentives. In this project, ECCR methodology will therefore be used. This methodology calculates the cost of electricity in the first year of operation. This cost would then be escalated with inflation to get cost of electricity in subsequent years. This eliminates risk for investors who are always worried about unsteady inflation rates in developing and undeveloped countries in general since the price can then be linked to inflation. Equation (12) gives the formula used to calculate the LCOE using the ECCR methodology [51].

$$LCOE = \frac{\left((ECCR \times Total\ installed\ cost) + Total\ O\&M\ Costs\right)}{Annual\ production\ of\ electricity} \qquad (12)$$

The excel model based on ECCR used in this project was adapted from the model used by NERSA to calculate the LCOE for REFIT. Table 5 shows the assumed project details used in the calculation of the LCOE in the model.

Table 5: Parameters used to calculate the LCOE for the base case

Assumption	Units	Value	Notes
Total Installed Capacity	MW	100	Calculation
Total net Capacity	MW	100	Capacity at metering point, taking auxiliary and losses into consideration
Unit Turbine Capacity	MW	2	Turbines used in DoE project ranged from 1.8-3.075MW
Number of units	#	50	Representative of REBID projects for 100MW wind farms
Plant construction lead time		1	Standard for onshore wind projects.

Table 6 below gives the low case, base case and high case values of the parameters that determined the economics of wind energy as discussed in section 6.

Table 6: Low Case, Base case and high case values used to calculate the LCOE

Parameter	**Low Case**	**Base Case**	**High Case**
Capital cost (USD/kW)	1,553.5	2,089.9	2,453.7
Discount rate (%)	10%	12%	14%
Capacity Factor (%)	24%	35%	40%
Project Lifespan (years)	15	20	25
Fixed Operation & Maintenance (USD/kW)	15	22	35

Since the calculation of the LCOE is central to the financial and economic assessments in this report, detailed calculation will be explained for the base case scenario using parameters given on Table 6.

Using equation (8), the Economic Carry Charge Rate (ECCR) per dollar invested is calculated using the PMT function as in equation (13).

$$
\begin{aligned}
&ECCR \\
&= PMT(Discount\ Rate, No.of\ payments\ (years), present\ value, future\ value, type) \\
&= PMT(0.12, 20, -1, 0, 1) \\
&= 0.119534625 \qquad (13)
\end{aligned}
$$

Future value is zero because it has been assumed that project lifespan is 20 years and after that, the value of scrap is equal to decommissioning costs. The type value is 1, meaning the payments are done at the beginning of the period (year).

$$
\begin{aligned}
Levelised\ capital\ cost\ (US\$/kW) &= ECCR\ \times capital\ cost/kW \\
&= 0.1195 \times 2089.9 \\
&= 249.8154 \qquad (14)
\end{aligned}
$$

Annual levelised capital cost per kWh is obtained by dividing the levelised cost per kW by the number of hours in a year and the capacity factor. For the base case, the capacity factor is 35%.

$$The\ annual\ levelised\ capital\ cost/kWh = \frac{249.8154}{8760 \times 0.35} = \$0.0815/kWh \qquad (15)$$

The levelised fixed operation and maintenance costs is $22/kW as per Table 6.

$$The\ annual\ levelised\ fixed\ operation\ and\ maintenance = \frac{22}{8760 \times 0.35}$$
$$= \$0.0072/kWh \quad (12)$$

Total levelised cost is obtained by adding values from equations (11) and (12).

$$Total\ levelised\ cost = \$(0.0815 + 0.0072)/kWh = \$0.08868/kWh$$
$$= R0.8868/kWh \qquad (16)$$

7.2.1 The results

From the model, the base case LCOE for wind is R0.8865/kWh (2013 base prices). When compared to Eskom's average tariff of R0,63/kWh (2013 base price), the wind LCOE is higher and would not compete.

When the base LCOE was benchmarked with LCOE in European countries, it was found that the LCOE is lower than for Spain, Germany, Netherlands and Switzerland. Figure 21 shows the comparison with wind farms in European countries that successfully rolled out wind energy [53]. REFIT was also included for comparison purposes.

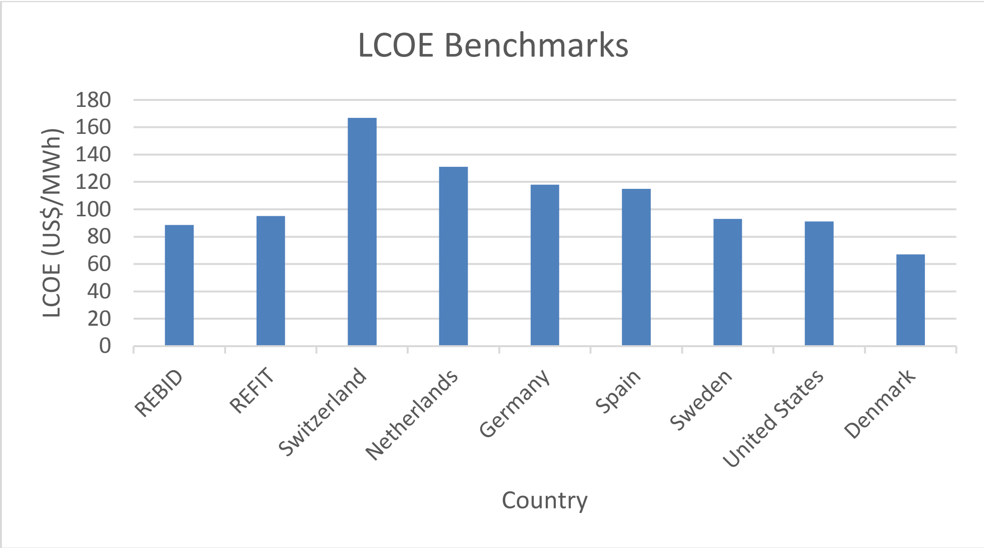


Figure 21: Comparison of REBID LCOE with international benchmarks (2013 base prices)

7.2.2 Sensitivity analysis

Wind resources was identified as the parameter with the most influence on economics and LCOE. To assess its impact, LCOE was calculated for different capacity factors and a graph was plotted as shown on Figure 22. This graphs shows that the LCOE, and therefore the economics of wind energy, is heavily dependent on the wind resources available. The LCOE is low at R0.7757/kWh at 40% capacity factor but becomes very high at R1.5515/kWh on low wind resources with capacity factor of 20%.

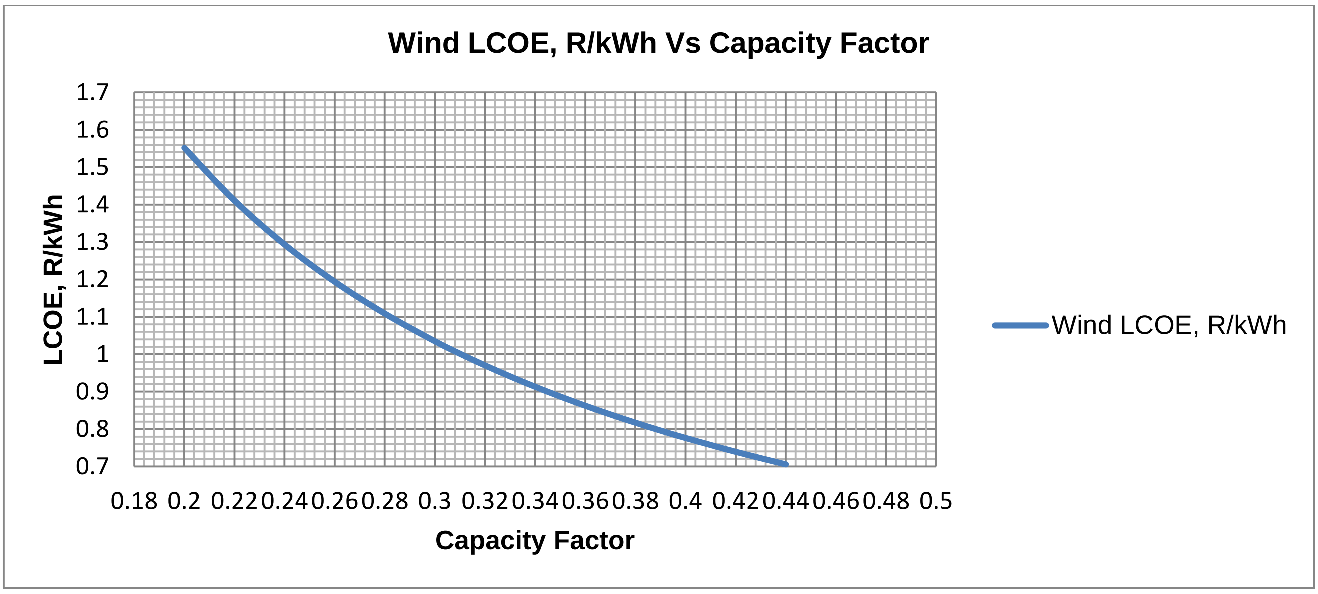


Figure 22: Variation of LCOE with capacity factor

Sensitivity analysis was also done on the rest of the parameters and results are shown on Figure 23 below.

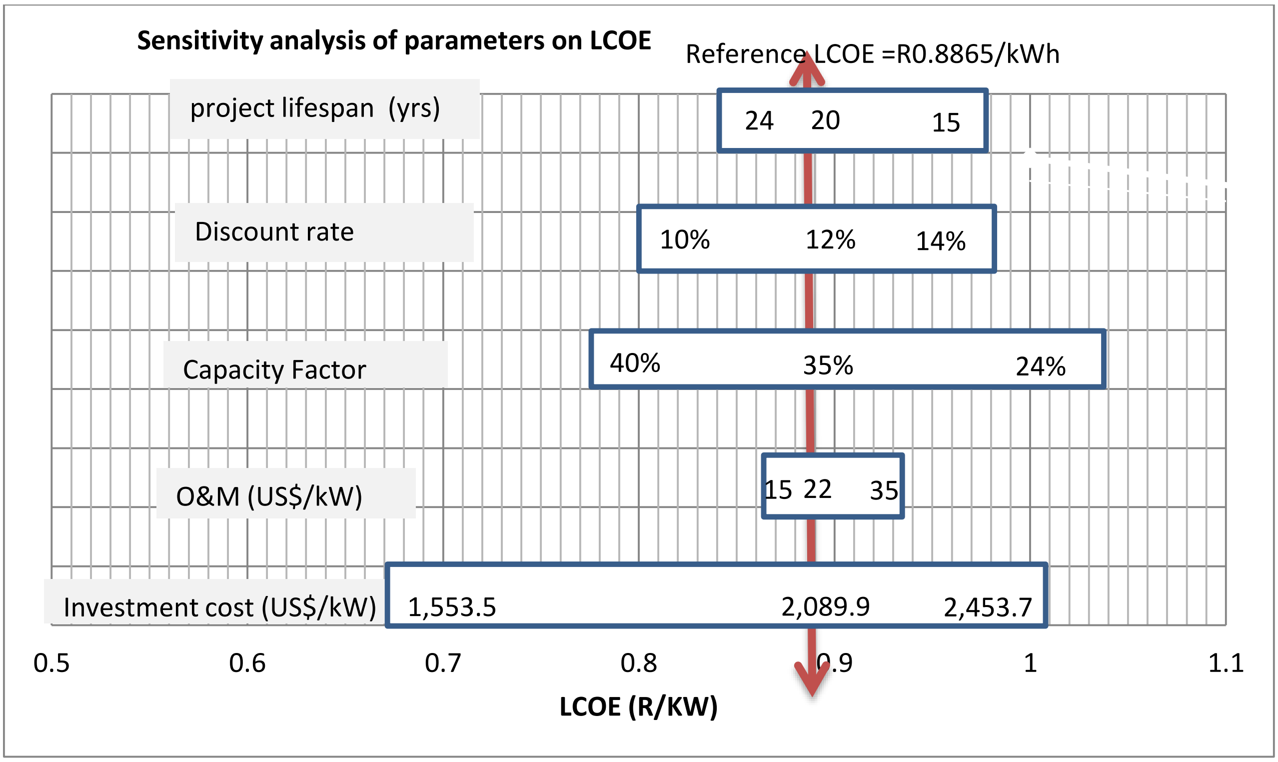


Figure 23: Sensitivity analysis of parameters affecting the LCOE

From Figure 22, it shows that LCOE is also very sensitive to the investment cost and the capacity factors followed by the discount rate. As the investment cost increases, the LCOE increases. The LCOE also increases as the discount rate increases.

7.3 Limitation of the model used to calculate the LCOE

The model did not take into account the revenue that the IPPs will get from selling renewable energy certificates on the international market. There was simply not enough information to include this benefit in the model.

7.4 Concluding Remarks

The REBID LCOE is very competitive at R0.8865/kWh. This value is comparable to some European countries that successfully implemented renewable energy such as Spain and Germany.

It has also been shown that the wind resources have the greatest impact on the economics of wind energy in South Africa.

8 CONCLUSION

The economics of wind generation depends on six parameters, namely, the wind resources, capital cost, the discount rate, the project lifespan and the operation and maintenance cost. Wind resources and the installation cost have the greatest influence on the economics of wind generation. Of these five parameters, the wind resources have the greatest influence. The wind atlas map developed by WASA and corroborated by capacity factors declared in REBID projects shows that South Africa has good wind resources, enough to support wind energy generation.

The research also shows that while the REFIT scheme was used successfully in European countries, it was not going to work in South Africa because firstly, it was not legally sound and might have faced legal challenges in the courts of law. Secondly, the REFIT rates that had been developed were too high as compared to what the bidders submitted in the REBID programme. This highlights the importance of properly setting the REFIT rates that are enough to attract investors but that would also prevent developers from getting windfall profits. South Africa's bidding scheme is the right instrument to deploy renewable energy in South Africa compared with the REFIT. From the results of the REBID, it shows that the country got good technology at competitive prices. Unlike in the UK where the tendering scheme failed to deliver projects, all round one and two projects were on schedule to reach scheduled COD as at November 2013[15].

The location of wind farms in South Africa will add other economic benefits such as job creation in remote areas, electricity expansion in those areas as well as reduction in technical losses. The only shortcomings of the South African bidding scheme are that it does not encourage local manufacturing of components and is also not suitable to local developers. High competition with international developers who have more financial muscle will stifle local developers.

To increase the economic benefits from wind generation, it is recommended that the subsequent bidding rounds incorporate local content for wind turbines manufactured.

[15]DoE's presentation to parliamentary Portfolio Committee on Energy, 5 November 2013.

This will attract wind turbine manufacturing in South Africa and the country might end up exporting to other African countries.

9 REFERENCES

1. Eskom Holdings SOC Ltd, "*Integrated 2012/13 Annual Report*", March 2013.

2. Wind Power Program;http://www.wind-power-program.com/turbine_characteristics.htm (Accessed 12 July 2013).

3. International Renewable Energy Agency (IRENA) "*30 years of policies for wind energy, Lessons from 12 Wind Energy markets*", 2012.

4. Department of Minerals and Energy, "*White paper on the Renewable Energy Policy of the Republic of South Africa*", Government Gazette no. 26169,Nov 2003.

5. Navigant Consulting, Inc, "*World Market Update 2012; International Wind Energy Development. Forecast 2013-2017*", March 2013,

6. European Wind Energy Association "*Wind Energy - The facts*", March 2009.

7. Mathew S, "*Wind Energy, fundamentals, Resource Analysis and Economics*", Springer, Netherlands, 2006.

8. Gipe P, "Wind Power", James & James (Science Publishers) Ltd, London, 2004.

9. ECOFYS, "*Financing Renewable Energy in the European Energy Market*", January 2011.

10. Ackermann T, "Wind Power in power Systems", John Wiley & Sons, Ltd, Chichester, 2005

11. http://www.teachergeek.org/wind_turbine_types.pdf(accessed 02 August 2013).

12. National Renewable Energy Laboratory; US Department of Energy, "*20% wind energy by 2030*".

13. Boston University, Mechanical Engineering Department; *Wind Turbines*, http://people.bu.edu/noahb/files/wind_turbine_main.pdf, (Accessed 7 September 2013).

14. Bloomberg New Energy Finance, *Q3 Clean Energy Policy and market briefing*, October 2012. *https://www.**bnef**.com/InsightDownload/7218/pdf/*, Accessed 7 January 2013.

15. International Renewable Energy Agency (IREA), "*Renewable energy auctions in developing countries*", 2013.

16. Fulton M, Capalino R. "*The German Feed-In Tariff: Recent Policy Changes*", September 2012

17. NERSA, "*Regulatory rules on network charges for third party transportation of Energy*", March 2012.

18. Eskom Holdings SOC Ltd, "*Annual Financial Statements*", 31 March 2013.

19. Eskom Holdings SOC Ltd, "*Integrated 2012/13 Annual Report*", 31 March 2013.

20. NERSA, "*The review of the Eskom Tariffs for the period 01 April 2012 to 31 March 2013*", March 2012.

21. European Commission, *Quarterly report on European Electricity markets, Vol 6, Issue 2*, Second Quarter 2013

22. Global Wind Energy Council, "*Global Wind Report, Annual Market Update*", 2012.

23. Edkins M. T, "*Reviewing Wind Energy Policy Risk in South Africa*", World Wind Energy Conference 2012, Bonn, Germany.

24. GreenStream,"*Opportunities to utilise tendering as a part of a feed in tariff system*", January 2010.

25. http://www.info.gov.za/speeches/2009/09062616151007.htm (accessed 03August 2013)

26. NERSA, "*Renewable Energy Feed –In Tariff Guidelines*", 2009

27. NERSA, "*Renewable Energy Feed –In Tariffs Phase II*", 2009

28. The European Wind Energy Association, "*The economics of Wind Energy*", March 2009

29. Szewczuk S, "*Wind Atlas for South Africa: Wind measurements and micro-scale modelling*", 2010

30. Szewczuk S, Prinsloo P, **"***Wind Atlas for South Africa (WASA): Project overview and current status*", CSIR Science Real and Relevant Conference, 2010.

31. Mortensen N. G et al, "*Observational Wind Atlas for 10Met. Masts in Northern, Western and Eastern Cape Provinces*", Dec 2012.

32. Wind atlas for South Africa (WASA), *Summary*.http://www.record.org.za/resources/documents-files/doc_download/27-wasa-summary-and-status, Accessed 22 September 2013.

33. Wind Resource Maps for WASA domain, South Africa, May 2013http://stel-apps.csir.co.za/wasa-data/grids/WASA%20wind%20resource%20information%20sheet%20v%20May%202013%20w.pdf; last accessed 7 September 2013.

34. http://www.windatlas.dk/europe/landmap.html, last accessed 22 September 2013.

35. Black & Veatch, "*Cost and performance data for power generation technologies*", February 2012.

36. Renewable Energy World.Com "*Energy World.com GE Snatches Wind Installation Crown from Vestas*", http://www.renewableenergyworld.com/rea/news/article/2013/02/ge-snatches-wind-installation-crown-from-vestas; (Accessed 15 September 2013.

37. ECOFYS, "*Policy instrument design to reduce financing cost in renewable energy technology projects*", October 2008.

38. ECOFYS, Financing Renewable Energy in the European Energy Market, January 2011

39. Electricity Regulation Act, 2006: Electricity Regulations on New Generation Capacity, R399 Government Gazette No 34262 of 4 May 2011.

39. Department of Energy media release on the Launch of First Wind Map; http://www.energy.gov.za/files/media/pr/2013/MediaRelease-First-large-Scale-High-Resolution-Wind-Resource-Map-Launched-31July2013.pdf, last accessed 7 September 2013.

40. National Treasury, Republic of South Africa, "*Policy paper for Public Comment: Carbon Tax*", May 2013

41. Bloomberg New Energy Finance, "*Vestas and GE were neck-and-neck for lead in wind's record year*", 18 April 2013. http://bnef.com/Downloads/pressreleases/298/pdffile/, Accessed 22 September 2013.

42. Department of Energy, "*Window two prefered bidders' announcement*", *May 2012*. http://www.energy.gov.za/IPP/Renewables_IPP_ProcurementProgram_WindowTwoAnnouncement_21May2012.pptx. Accessed 20 December 2013.

43. IRENA, "*Renewable Energy Technologies: cost Analysis Series, Wind Power*". Vol 1 Power Sector Series, issue 5/5, June 2012.

44. Engineering News, *Absa commits R10.8bn to REIPPP renewable energy projects*. http://www.engineeringnews.co.za/article/absa-commits-r108bn-to-reipppp-round-3-projects-2013-11-11/rep_id:3182, Accessed 18November 2013

45. Engineering News, *Nedbank provides debt funding for seven REIPPPP 3 projects*, http://www.engineeringnews.co.za/article/nedbank-provides-debt-funding-for-seven-reipppp-3-projects-2013-11-08/rep_id:3182?utm_source=Creamer+Media+FDE+service&utm_medium=email&utm_campaign=Sapvia+calls+for+more+renewables+capacity+%7C+SA%2C+DRC+plan+regional+bilaterals+%7C+Investments+remain+protected%2C+assures+Davies&utm_term=http%3A%2F%2Fwww.engineeringnews.co.za%2Farticle%2Fnedbank-provides-debt-funding-for-seven-reipppp-3-projects-2013-11-08%2Frep_id%3A3182, Accessed 18November 2013.

46. Engineering News, *Futuregrowth provides R165million for five projects*,http://www.engineeringnews.co.za/article/futuregrowth-provides-r165-million-for-five-reipppp-projects-2013-11-27/rep_id:3182.

47. Eskom Transmission Development Plan 2013 – 2022, October 2013

48. US Energy Information Administration, "*Assumptions to the Annual Energy Outlook"*,http://www.eia.gov/forecasts/aeo/assumptions/pdf/electricity.pdf.Accessed 20 December 2013.

49. Fraunhofer Institut for Solar Energy Systems ISE, "*Levelized cost of electricity renewable energies"*, May 2012.

50. Short W, Packey D.J, Holt T, "*A manual for economic evaluation of energy efficiency and renewable energy technologies"*, March 1995.

51. NREL, Renewable Energy Cost Modelling: *A "Toolkit for establishing cost-based incentives in the United States"*, May 2011.

52. NERSA, *Determination of the municipal tariff guidelines for the financial year 2013/14 and revision of the municipal tariff benchmarks*, March 2013.

53. IEA Wind Task 26, *Multi-national Case Study of the financial cost of wind*, March 2011

54. Fraunhofer Institut for Solar Energy Systems ISE, "*Levelized cost of electricity renewable energy technologies"*, November 2013