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Developing Wind Power in South Africa: A Sustainable Means to Satisfying South Africa's Energy Demand

Emma F. Micklem

Supervisor: Johannes Mauritzen
External Advisor: Naveen R. Balachandran, Vestas

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Abbreviations

AWEA	American Wind Power Association
BEE	Black Economic Empowerment
CaBEERE	Capacity Building in Energy Efficiency and Renewable Energy
CDM	Clean Development Mechanism
CO_2	Carbon Dioxide
DEAT	Department of Environmental Affairs and Tourism
DME	Department of Minerals and Energy
EDI	Electricity Distribution Industry
Eskom	Electricity Supply Commission of South Africa
GDP	Gross Domestic Product
GW	Giga Watt
GWh	Giga Watt Hour
IPP	Independent Power Producer
km	Kilometre
km/h	Kilometre per hour
kW	Kilowatt, 10^3 Watt
kWh	Kilowatt-hour(s), 10^3 Watt-hours
m	Metres
m/s	Metres per second
Mtoe	Million tons of oil equivalent
MW	Megawatt, 10^6 Watt
MWh	Megawatt-hour(s), 10^6 Watt-hours
NERSA	National Energy Regulator of South Africa
PPA	Power Purchase Agreement
RED	Regional Electricity Distributor
REFIT	Renewable Energy Feed-In Tariff
REPA	Renewable Energy Power Purchase Agency
RSA	Republic of South Africa

SABRE-Gen	South African Bulk Renewable Energy Generation
TW	Terawatt, 10^{12} Watt
TWh	Terawatt-hours, 10^{12} Watt-hours
WAsP	Wind Atlas Analysis and Application Programme
ZAR	South African Rand

Abstract

The South African electricity industry is easily the largest in Africa, yet it has been unable to meet the country's energy demands, despite the country's mass-electrification programme. Power cuts since late 2007 have become standard practice, while close to a third of the country's households are not connected to the grid. South Africa also faces environmental problems, particularly in the form of water shortages, and is in the top quartile for most CO_2 equivalent gases released by a country. This report evaluates wind power as a sustainable solution to increasing South Africa's electricity generating capacity. To identify the country's wind energy potential, the resource conditions are examined, followed by an analysis of the electricity industry and incentives that aim to promote the adoption of renewable energy. The findings indicate that the country has abundant locations with favourable wind conditions. It is also apparent that new sustainable generation capacity is required and that the recently introduced governmental incentives render certain renewable energy technologies economically feasible.

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Chapter 1: Introduction and Problem Statement

1.1 Introduction

This study of the South African wind power market potential is compiled in three major parts. The wind resource is assessed, followed by an examination of the local business and energy markets, and concluded with an overview of the renewable energy incentives.

South Africa has an abundance of windy regions across the land. This energy source’s primary benefits are that its fuel is free and sustainable. It is also one of the few renewable energy sources that do not require the use of water; a scarcity in many parts of the country. While wind power cannot be efficiently stored, the daily wind power cycle happens to be a close match to that of the power demand cycle. Thus it is often the case that local wind speeds reach their highest as national energy demands peak.

Evaluating the conditions of South Africa’s wind resource shows that the primary potential for wind power projects lies along the coastline and especially on the West Coast. This is due to the natural wind speeds and land topography. The existing infrastructure poses little concern as the electricity grid and road systems are well-connected apart from some remote inland locations. Considering that a wind power project’s feasibility is in many cases based on its proximity to transmission lines and roads, highlights the country’s advantageous conditions.

Despite successfully connecting two million households to the grid over a six year period as part of the national electrification programme, a third of the population still remains without access to electricity. South Africa’s reserve power capacity hit its lowest levels in 2007 which has since resulted in wide-spread power shortages. The electricity demand is forecasted to increase steadily for at least another 25 years, amplifying the need for a rapid increase in generation capacity. Some of this new capacity must be sustainable in order for the government to reach its White Paper’s target. Though the country does not face any internationally binding emission reduction targets, its own goal is an ambitious one. If achieved, the country will limit its reliance on coal which is associated with substantial water use and relatively high CO_2 equivalent emissions.

Until recently, renewable energy sources in South Africa could not compete with the cheap price of coal. In 2003 the government saw the need to create a financial incentive to encourage the development of renewable generating capacity. This incentive eventually came in the form of a feed-in tariff in 2009, which provides renewable energy generators with the guaranteed sale of their power at a given price. The incentive has rendered certain renewable energy sources economically viable and has resulted in an influx in project applications to the government.

This study develops the notion that wind power may be the solution to meeting South Africa's energy demand. The favourable wind conditions and grid infrastructure, along with the growing electricity demand and recent introduction of the feed-in tariff, are reasons for this argument.

During this study, the focus will remain on grid-connected, on-shore wind power resulting from the fact that the renewable energy incentives do not include off-grid and off-shore wind power projects. Financial aspects are reported though a complete economic evaluation is outside the scope of this study.

1.2 Problem Statement

Since 2007, South Africa has experienced power shortages due to the lack of new power generating capacity, the result of which has been a loss in confidence in the country's economy and substantial financial deficits for both the public and private sector. Environmental issues in terms of water shortages and carbon emissions in the atmosphere are also becoming increasingly pertinent. To combat these problems, the government has put a number of incentives in place for renewable energy to meet the growing electricity demand. The goal of this work is to provide the framework in which market entrants can evaluate the South African wind power market potential.

Chapter 2: The Wind Resource

South Africa's wealth of wind resources combined with its land availability and grid infrastructure makes it an ideal location for wind power projects. These conditions have the potential to make the country's wind power among the most economically efficient for bulk electricity generation in the world (Tripod Wind Energy & Oelsner Group, 2003). The resource's abundance is evident in the well-established market for farm wind mills that scatter the land. These wind mills are primarily used as a cheap and easy source of water pumping that is used for livestock and agricultural purposes (Karottki, Schäffler, & Banks, 2001).

In terms of wind power for electricity generation, South Africa is still in the development phase. Two demonstration projects totalling 8.36 MW are currently in operation and both project operators confirmed that the low national electricity price rendered the projects economically uncompetitive (Karottki, Schäffler, & Banks, 2001). The recent inclusion of a feed-in tariff aims to alter this. Foreign and local investors have since shown increased interest, many of whom have guaranteed funding for the project and are simply awaiting licenses (Genesis Eco-Energy, 2009).

2.1 Wind Power

South Africa's wind is dominant along the country's coastline and especially along the West Coast, where the cold Benguela ocean current meets the warm coastal temperatures. Wind speed averages of over 4 m/s have also been measured inland which often indicates wind speeds above 6 m/s in amplified areas, such as hill tops (Jargstorf, 2004). The national wind resource is evaluated using tools prescribed by the American Wind Energy Association (AWEA) which are provided in more detail in Annex 1.

The power in the wind relates to the potential energy that can be extracted from the resource (AWEA, 2009). The formula for the power in the wind (Watt), which is essentially the power output of a wind turbine, is:

$$\text{power in the wind} = \tfrac{1}{2} A\rho V^3$$

where A is the area which the turbine blades sweep (m^2), ρ is the air density (kg/m^3), and V is the wind speed (m/s) (Smit, van Heerden, & Smit, 2008). Air density is affected by temperature, ambient air pressure and humidity while wind speed is affected by factors such as seasonality and land topography.

2.1.1 Wind Speed

Wind speed increases a turbine's power output exponentially, making it the principal criteria for wind power evaluation. Wind speed is categorized in different classes (see Table 1) for which the AWEA (2009) suggests that annual classes of at least 3 are required for grid-connected applications, while a wind power class of 5 or more is ideal. Conditions are also greater at higher altitudes which explains why most turbines stand at a height of more than 80 m.

Table 1: Wind power classes (AWEA, 2009)

Wind power class	10 m		50 m	
	Wind power density (W/m^2)	Speed (m/s)	Wind power density (W/m^2)	Speed (m/s)
1	<100	<4.4	<200	<5.6
2	100 - 150	4.4/5.1	200 - 300	5.6/6.4
3	150 - 200	5.1/5.6	300 - 400	6.4/7.0
4	200 - 250	5.6/6.0	400 - 500	7.0/7.5
5	250 - 300	6.0/6.4	500 - 600	7.5/8.0
6	300 - 400	6.4/7.0	600 - 800	8.0/8.8
7	>400	>7.0	>800	>8.8

Note: Vertical extrapolation of wind speed based on the 1/7 power law

Diab (1995) developed the first wind atlas of South Africa for which wind measurements were made at a 10 m height. Figure 2 depicts Diab's conclusive results, showing that the coast in its entirety had mean wind speeds of over 4 m/s, while a large part of the interior measured between 3 and 4 m/s.

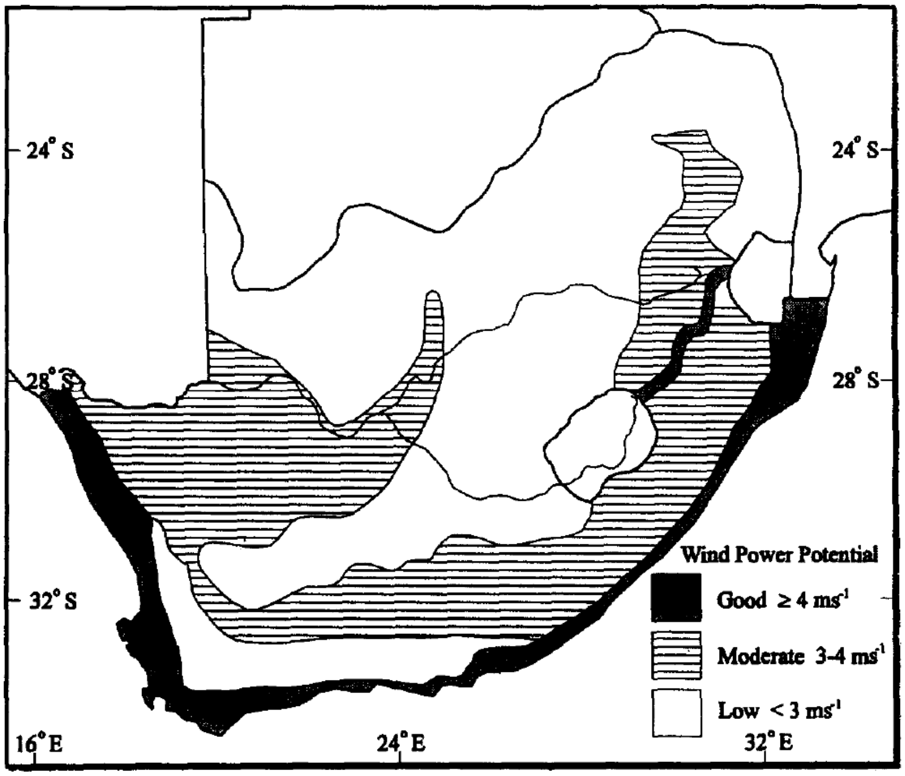


Figure 2: Wind atlas of South Africa (Diab, 1995)

In 2004, Jargstorf's results confirmed Diab's earlier findings. Data points were obtained from meteorological stations across the country and provide specific wind speeds in numerous locations (see Annex 2). The South African Bulk Renewable Energy Generation (SABRE-Gen) programme also developed a wind database using the Wind Atlas Analysis and Application Programme (WAsP) in 2001 (SABRE-Gen Energy, 2009). However, this data is incomplete and shows some discrepancies with the previously mentioned studies.

The most recent and most convincing wind resource study was developed by Hagemann (2009). His mesoscale model was based on data from March 1996 to March 1997, which was found to be the best representative 365 day period between the years 1993 and 2004. The data obtained at a 10 m height was extrapolated over 18 km^2 regions in which the land surface was smoothened out. The results validated those of Jargstorf (2004) and provide a more complete, though less specific, wind atlas (see Figure 3).

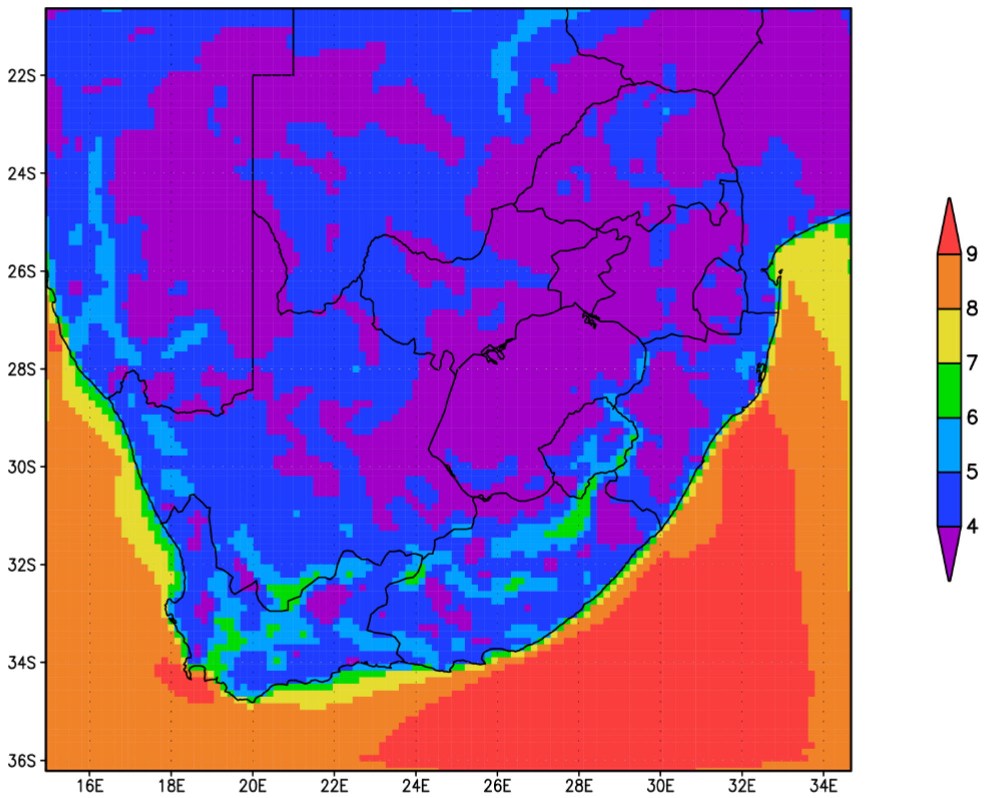


Figure 3: Wind atlas of South Africa (m/s) (Hagemann, 2009)

This atlas made evident that wind classes of 5 and 6 were common along the country's coast with off-shore wind speeds reaching an attractive class 7.

These wind speeds are subject to surface qualities, such as obstacles, roughness and elevation (Hansen, Jørgensen, Hahmann, & Mortensen, 2009). A 5% increase in elevation can result in a proportionate increase in wind speeds, which effectively increases the power in the wind by a power of 3. South Africa's total land area is slightly more than 1.2 million km^2, making it roughly one eighth the size of the US and twice the size of France (South Africa Info, 2009). The country's long coastline, stretching more than 2,500 km, is low-lying and fairly narrow. The mountainous escarpment begins anywhere between 60 and 240 km from the coast and leads to the high inland plateau (see Figure 4). Comparing the country's wind speeds to its topography demonstrates that wind speeds increase as the escarpment reaches the plateau of roughly 1,200 m above sea level.

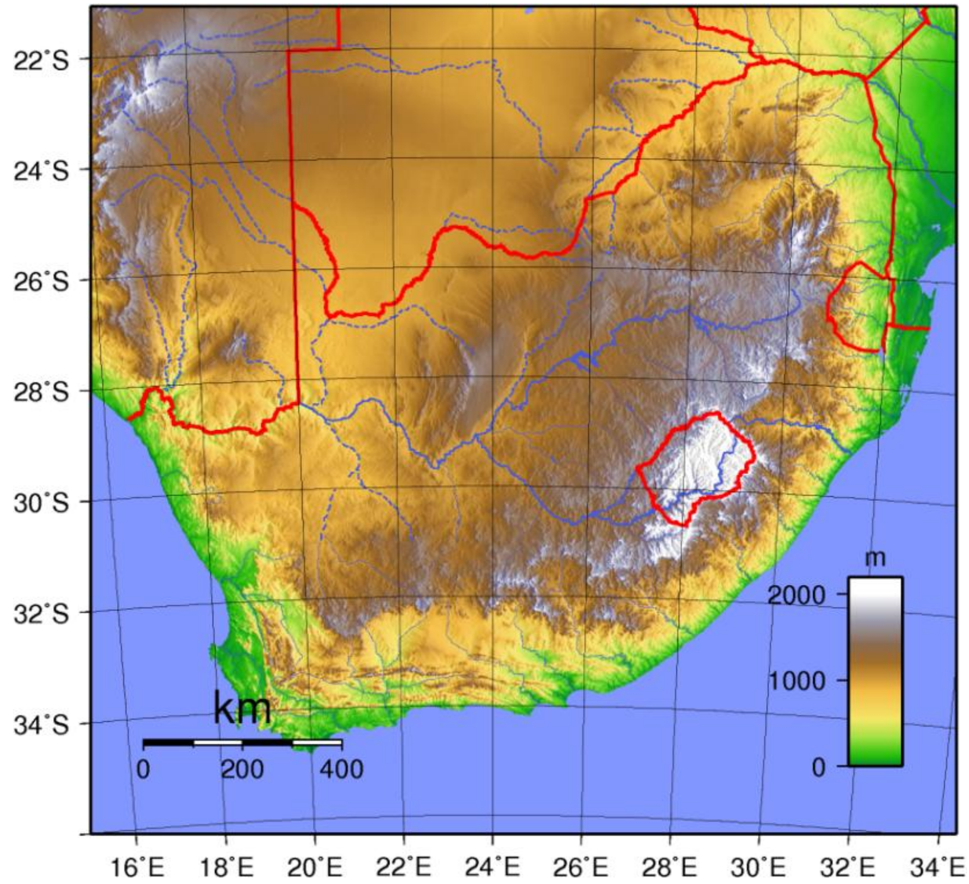


Figure 4: South African topographic map (DEAT, 2000)

2.1.2 Wind Power Cycle

In South Africa, the wind tends to blow at greater speeds during the day and to fade away during the night. Hagemann's (2009) two examples of average wind speeds during a 24-hour period are presented in Figure 5. Alexander Bay is located on the West Coast near the Namibian border and Bloemfontein is located inland in the centre of South Africa. There is a substantial difference in wind speeds at the two locations yet their cycles are fairly similar.

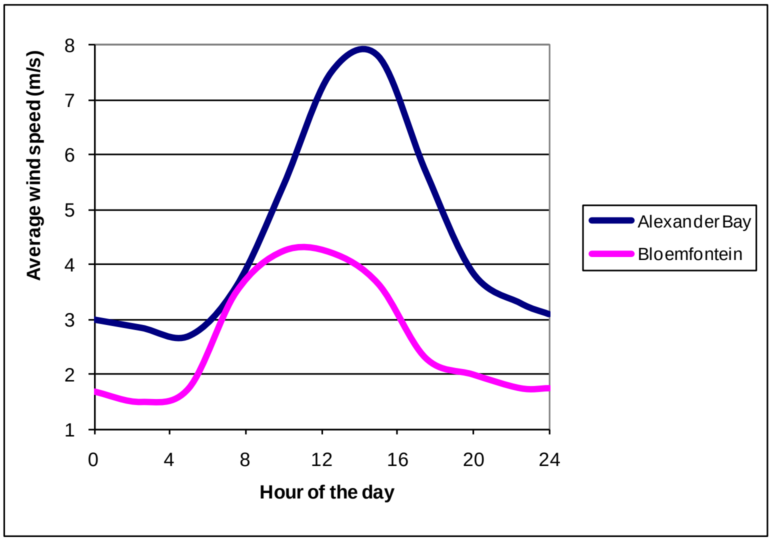


Figure 5: Wind cycles for Alexander Bay and Bloemfontein respectively (Hagemann, Mesoscale Wind Atlas of South Africa, 2009)

Monthly comparisons for these two locations were drawn from a complete database of South African weather stations, namely Routes (2009). The 2009 recordings are presented in Annex 3. They depict one month in summer (January) and one month in August (winter). From the monthly graphs it is evident that wind speeds commonly peak near midday. Wind speeds are also stronger in summer months for these locations, though this is not the case across the country. Different regions are subject to their own seasonal factors. For example, Cape Town has a high rainfall in winter while Johannesburg has a high rainfall in summer. Due to differences in temperature and humidity, the wind power from region to region will exhibit different patterns.

South African wind cycles and electricity demand patterns are a near ideal match. Hagemann's (2009) research shows that daily wind cycles along coastal areas is within roughly one hour of peak electricity demand, while conclusive findings for inland sites were not reported. In 2005, the average daily cycle for the whole country followed the pattern depicted in Figure 6 (Global Energy Decisions, 2006). Peak demand was roughly from 8am to 12pm and from 5pm to 9pm, while the demand ranged between roughly 20,000 and 27,000 MW.

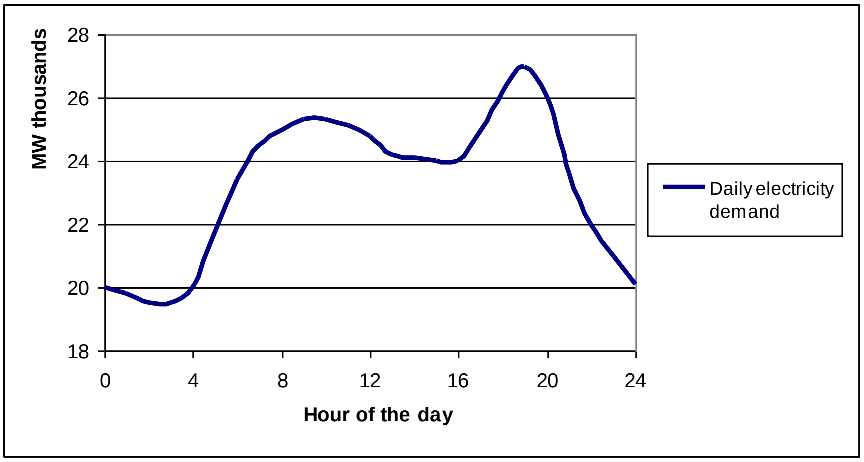


Figure 6: Average daily electricity demand profile for 2005 in South Africa (Global Energy Decisions, 2006)

The recent 2009 Eskom Annual Report shows that the average daily demand profile has started to shape more like one of a developed economy (see Figure 7) (Eskom, 2009). Peak periods are now closer to 7am to 1pm and 5pm to 10pm, while the demand ranges from roughly 23,000 MW to 36,000 MW. It is evident that as total electricity demand rises, the average daily peak demand increases more significantly.

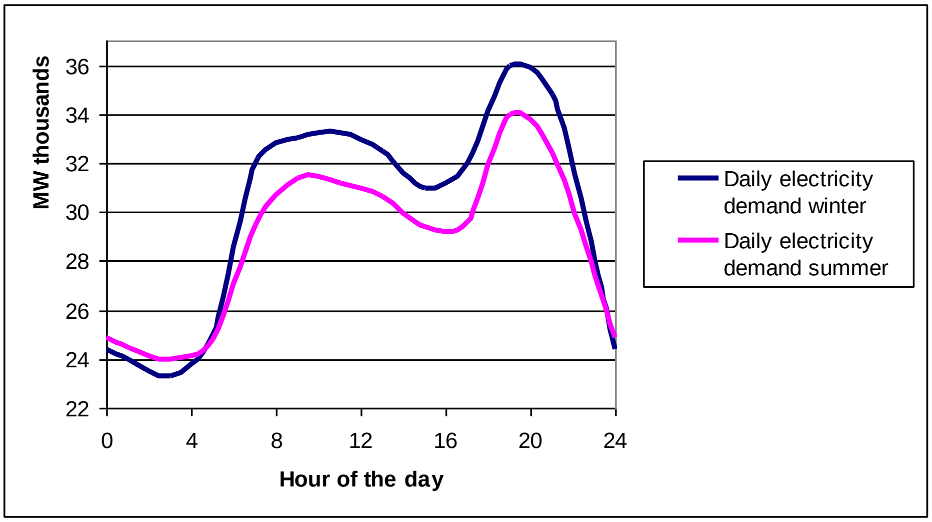


Figure 7: Electricity demand patterns 2008 (Eskom, 2009)

2.2 Grid Infrastructure

A wind farm's proximity to transmission lines and, to a lesser extent, its proximity to roads is critical to a project's feasibility (Hagemann, Mesoscale Wind Atlas of South Africa, 2009). The South African grid comprises 28,236 km of high voltage lines, mostly in the range of 275 to 400 kV (Eskom, 2009). The country is well-connected apart from a few remote inland areas. Nonetheless, potential problems lie in the overloading of power plants and incorrect or poor maintenance services (Vestas, 2008). These issues may be augmented by the attributes associated with wind power, such as intermittency in supply, inaccurate long-term predictability, lack of adequate storage possibilities and transmission losses.

2.2.1 Transmission Lines and Substations

Wind farms are connected to different transmission line voltages depending on the farm's capacity. Hagemann (2009) noted in an interview that the voltage requirements vary depending on multiple factors, such as loads in the area and conductor sizes. Notwithstanding these factors, the guideline figures, and which transmission line they are associated with, are presented in the table and diagram below.

Table 2: Wind farm capacity and transmission line voltage requirements (Hagemann, Grid Infrastructure, 2009)

Wind farm capacity (MW)	Transmission line voltage (kV)	Corresponding colour in map
10-40	66	Red
60-120	132	Blue
150-220	220	Yellow
Larger than 300	Larger than 400	Purple

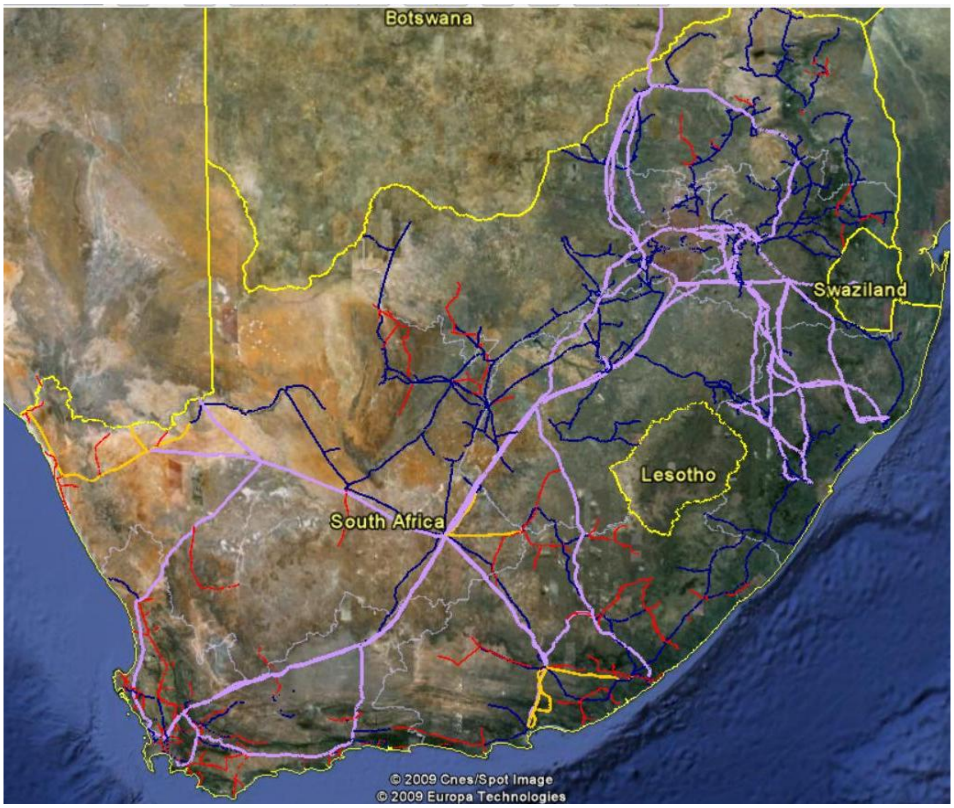


Figure 8: South African transmission lines and respective voltages (Hagemann, Grid Infrastructure, 2009)

An additional limitation is the proximity of a wind farm to a transmission substation. This is due to the fact that shorter distances result in lower construction and connection costs, while it also minimizes transmission losses. Vestas targets wind farm sites which are located less than 10 km to the nearest transmission substation, while the substation itself should be less than 20 km from the loading point (Balachandran, 2009). Information on substation locations is not openly available and is cause for further analysis.

2.2.2 Transmission Loss Minimization

Considering transmission losses is critical in determining a location in which costs are minimized. Eskom charges consumers for transmission losses based on their distance away from Johannesburg; the city from which the majority of power is distributed (Eskom, 2009). Figure 9 displays the distances at which the electricity charge increases. It is evident that South Africa’s West Coast and southern tip, which encompasses close to the entire Western Cape and part of the Northern Cape, faces the largest transmission losses and thus, the highest electricity charge.

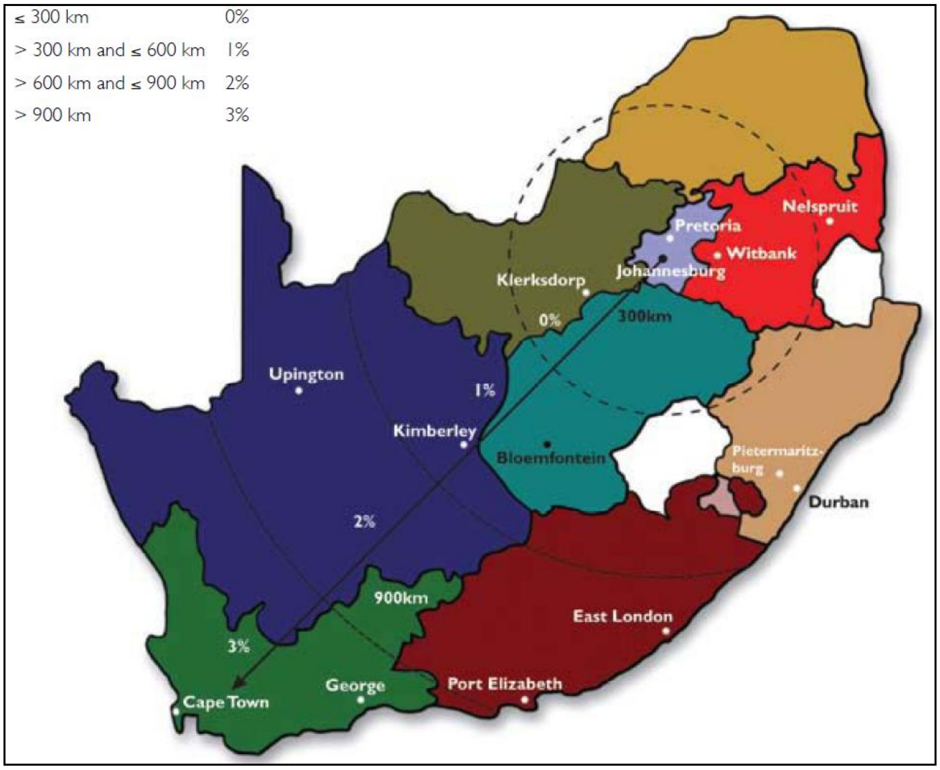


Figure 9: Transmission zones and tariff percentages (Eskom, 2009)

This region has one major power plant, namely the nuclear station located near Cape Town (Eskom Website, 2009). The nuclear plant has a capacity of 1,930 MW and supplies roughly 6% of the country's electricity demand. However, in 2005 the Western Cape alone consumed 10.7% of South Africa's electricity (Global Energy Decisions, 2006). The Western Cape was also the first and hardest hit province during the electricity shortages faced in 2007 and 2008 (Eskom, 2009).

2.3 Location Analysis

In merging the previously mentioned aspects of wind speeds, land topography and proximity to transmission lines, the focus can be narrowed down to certain promising regions within South Africa. It is apparent that wind speeds are especially high along the coastline. In addition, while coastal demand accounts for 34% of total demand, it only accounts for 6% of the country's generating capacity (Global Energy Decisions, 2006). Taking transmission losses into account, the West Coast and southern tip of the country have the most potential to minimize consumer costs and possible power outages. Owing to the Western Cape's substantial electricity demand and longest coast line in the high transmission loss area, this province serves as an example in the following section.

2.3.1 Western Cape

The Western Cape climate constitutes hot, dry summers and cold, wet winters (South Africa Info, 2009). Gale-force winds are frequent along the coastline; the West Coast usually experiences southerly and north-westerly wind directions season dependent, and the south coast experiences roughly north-westerly and south-easterly winds. Wind speeds also pick up in the interior along the mountain ridges diagonally towards the north-east (see Figure 10).

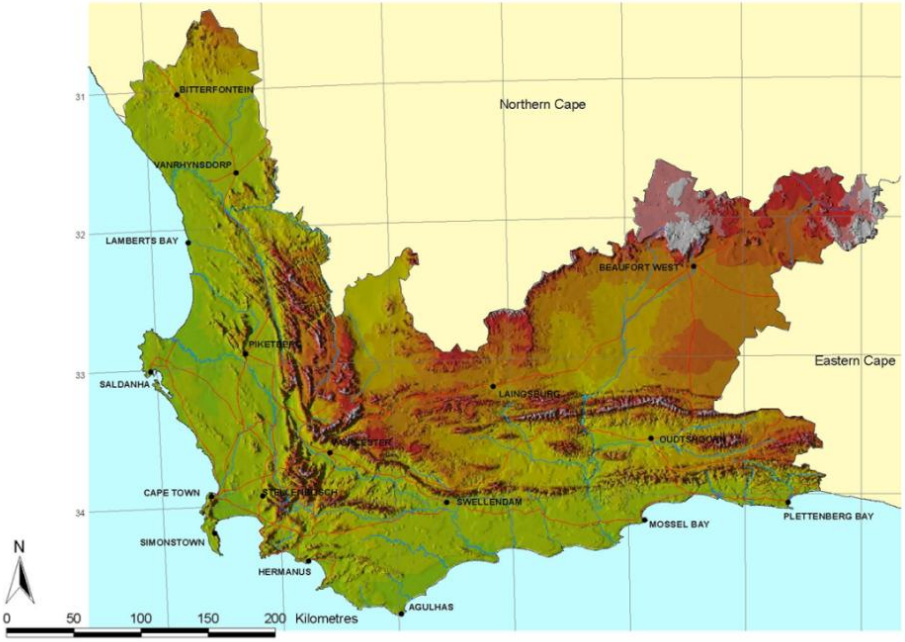


Figure 10: Western Cape land topography (DEAT, 2000)

A combination of Hagemann's (2009) mesoscale model and the transmission grid for the Western Cape demonstrates the proximity to which locations with favourable wind speeds are from transmission lines (see Figure 11).

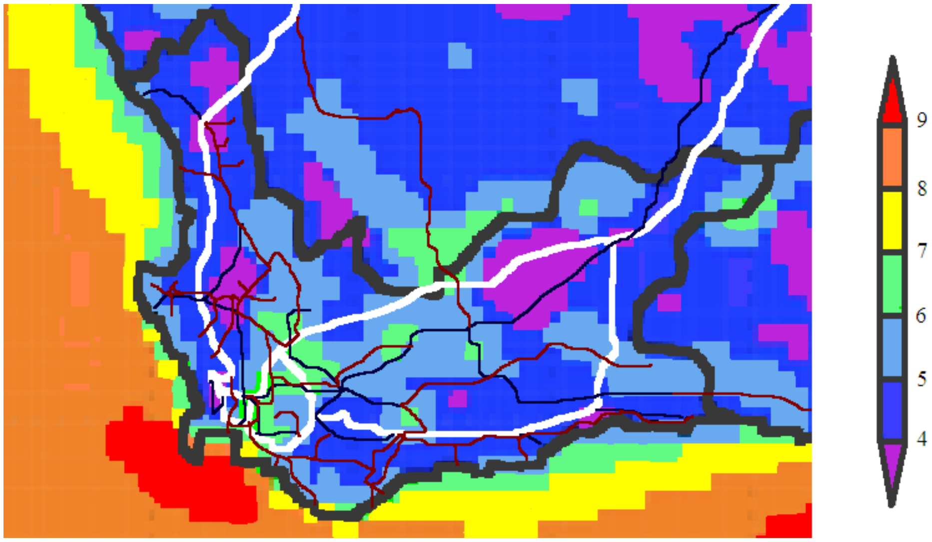


Figure 11: Western Cape transmission grid and wind speeds (Hagemann, Grid Infrastructure, 2009) (Hagemann, Mesoscale Wind Atlas of South Africa, 2009)

The white (>400 kV), blue (132kV) and red (66 kV) transmission lines illustrate that areas with a wind speed of 6 m/s or greater are relatively close to the grid. Data on wind directions and the duration of each wind speed (in terms of a WAsP output as shown in an example in Annex 4) is necessary for further assessment. The figure also excludes elements of proximity to roads, yet the Western Cape is well connected and most areas are easily accessible. Further analysis is required for substation locations and load capacities.

Chapter 3: The Market

3.1 Business in South Africa

3.1.1 The Economy

South Africa is a democratic country with world-class development in its governmental, legal and commercial sectors. Even so, it is faced with issues common to that of developing nations, such as unemployment, income inequality and criminality.

South Africa's economic growth has been strong in recent years yet it was still plagued by its outdated infrastructure. The positive economic performance the country has experienced since 1999 led to growth in energy demand that could not be met by the existing infrastructure, eventually leading to electricity demand outstripping supply in late 2007 (South Africa Info, 2009). Major cities experienced power cuts which not only caused large financial losses to local businesses, but also resulted in a loss of confidence in the country's economy.

South Africa boasts the largest economy in Africa with its leading position in industrial output and mineral production (South Africa Info, 2009). South Africa's progressive legal framework and financial systems are solid, while its banking sector is sophisticated and competitive on a global level. The country's annual economic growth rate has averaged over 4% since 1999 and over 5% in 2007 and 2008 due to macroeconomic stability and a global commodities boom (Index Mundi, 2009). The lower growth of 3.1% in 2009 was due to the financial crisis which impacted the country later than its Western counterparts.

The CIA World Factbook describes South Africa's economic policy as:

> *'...fiscally conservative but pragmatic, focusing on controlling inflation, maintaining a budget surplus, and using state-owned enterprises to deliver basic services to low-income areas as a means to increase job growth and household income.' (Index Mundi, 2009)*

Unemployment in the population of roughly 49 million is slowly decreasing. However, the unemployment rate remains high at 22.9% aggravating the poverty gap and associated criminality (Index Mundi, 2009). This is attributed to low education levels and wide spread health issues, such as Tuberculosis and HIV/AIDS of which the latter is estimated to be prevalent amongst 18.1% of the adult population.

Economic empowerment policies for previously disadvantaged groups (for example, non-white races, women and the disabled) have been put in place to bridge the poverty gap and promote equality. The Black Economic Empowerment (BEE) policy of 2003 evaluates companies for their contribution to these previously disadvantaged groups (South Africa Info, 2009). The measured areas are direct empowerment through ownership and control of enterprises and assets, management at senior levels, human resource development and employment equity, and indirect empowerment (namely preferential procurement, enterprise development, and corporate social investment).

3.1.2 Business Operations

The World Bank Group's (2009) results from a South African study on factors that affect business practices are shown in Annex 5. South Africa was ranked 34th out of 182 economies for the ease of doing business criteria (see Table 33). Local businesses generally have access to credit and benefit from good investor protection laws and an advantageous tax system. Getting credit, protecting investors and paying taxes abidingly were ranked even better for local businesses. However, businesses are faced with problems when trading across borders, due to the number of procedural documents involved, long lead times and high export and import prices. The large portion of unskilled labour in the workforce is also a concern.

Table 3: South Africa's ranking on business creation criteria (World Bank Group, 2009)

Criteria	Rank
Ease of Doing Business	34
Starting a Business	67
Dealing with Construction Permits	52
Employing Workers	102
Registering Property	90
Getting Credit	2
Protecting Investors	10
Paying Taxes	23
Trading Across Borders	148
Enforcing Contracts	85
Closing a Business	76

In terms of corruption, Transparency International (2008) evaluated 180 countries based on worldwide surveys of country specialists, business officials and human rights monitors. The index it developed has a scale of 0 to 10, with the lowest number indicating the highest percentile of corruption. South Africa ranks 54th least corrupt and has a Corruption Perception Index of 4.9 among countries such as Latvia and Italy.

3.1.3 The Environment

South Africa emitted 345.8 million tonnes of CO_2 in 2007, a 35.8% increase from 1990 levels (IEA, 2009). On a per capita basis however, the increase was only 0.4% from 1990 levels, totalling 7.27 tonnes of CO_2 per capita. Relative to the rest of the world, South Africa falls between 30th and 50th (depending on the calculation method used) for the most greenhouse gas polluting nation per capita.

South Africa is a semi-arid country facing water shortages on an annual basis (Index Mundi, 2009). Thus water conservation and control measures are becoming increasingly important. More than 50% of South Africa's water is used as irrigation for agricultural purposes, while over 10% is used in the industrial, mining, commercial and power generation sector (Department of Water Affairs and Forestry, 2003).

3.2 The Electricity Industry

3.2.1 Generating Capacity and Growth Forecasts

South Africa's National Electrification Programme aimed to provide 'electricity for all' (Marquard, Bekker, Eberhard, & Gaunt, 2007). Despite successfully providing 1,000 households with electricity each day between 1994 and 2000, a third of the population still remains without access to electricity. Even so, the country has a significantly larger electricity industry than other African countries. Total electricity consumption in 2008 was 241 TWh while the second largest market in Africa was Egypt's 91 TWh (Index Mundi, 2009). Electricity is also exported and imported during peak demand to and from South Africa's neighbouring countries.

Total generating capacity, including small power stations, was near 39 TW in 2008 though availability was usually closer to 30 TW (Eskom, 2009). Growth in capacity was stagnant from 2002 to 2006, while demand continued to grow between 2 and 3% per annum (see Figure 12). In 2007 and 2008 the reserve margin hit a dangerous low of 8 to 10% in comparison to 20% in 2004. The targeted reserve margin for South Africa is a minimum of 15% to allow power plants to operate at levels in which equipment is not highly stressed as well as to allow for maintenance (South African Government Information, 2008).

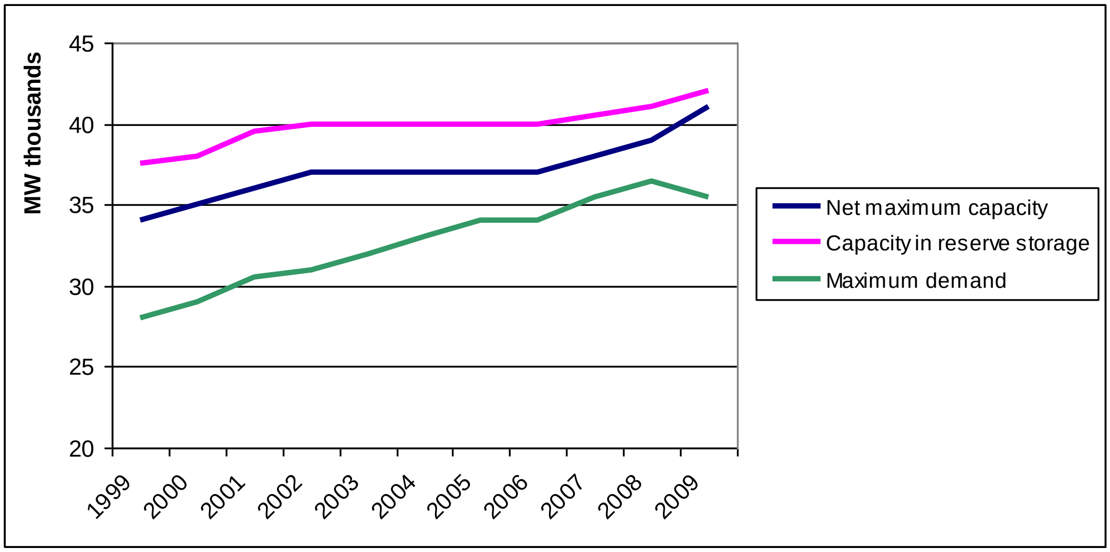


Figure 12: Generation plant capacity and maximum generation (Eskom, 2009)

The intermittency in the supply of wind power requires the availability of reserve capacity to counter any sudden energy shortages (Danish Wind Industry Association, 2003). Hence, South Africa's current reserve capacity is not favourable for an unreliable energy supply. Using an intermittent energy source in combination with another flexible renewable source for which output can be changed quickly, such as hydro power, eliminates this issue.

South Africa's electricity consumption is expected to continue its growth of roughly 3% per annum if normal growth in GDP is established at 4.6% (see Figure 13) (Eskom, 2009). Capacity will in turn need to increase rapidly to ensure the stability of electricity supply. The government plans to secure additional capacity by offering financial incentives for new capacity builds in both the fossil and renewable energy industries.

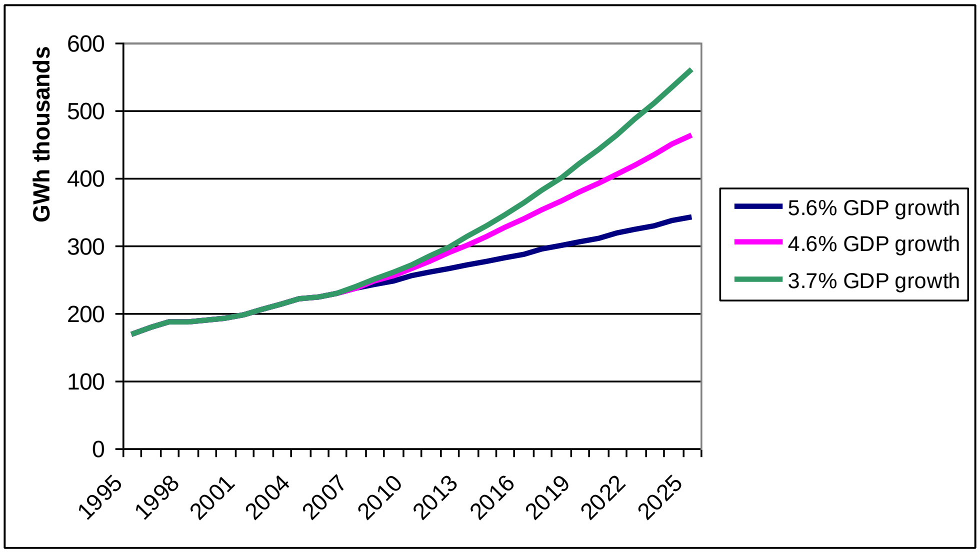


Figure 13: National and foreign electricity sales forecasts (Eskom, 2009)

3.2.2 Regulators

The electricity industry is managed by the South African Department of Minerals and Energy (DME) which has the responsibility to ensure that the White Paper's targets are met (DME Website, 2009). In 1998, the White Paper aimed to restructure the industry into six viable Regional Electricity Distributers (REDs). This had the dual intention of creating an environment in which the country's electrification programme could be rolled out more effectively while also creating an efficient market through increased competition in the electricity sector.

The electricity supply is overseen by the National Energy Regulator of South Africa (NERSA) (herein referred to as the Regulator). The Regulator developed the renewable energy tariff known as REFIT to achieve its goals of increasing competition and boosting economic growth (NERSA Website, 2009). The Regulator has the authority over REFIT and can set limits on companies' subscriptions to receive the tariff. It has also mandated a separate entity to oversee the licensing and receiving of the tariff called the Renewable Energy Purchasing Agency (REPA) (NERSA, 2009).

For a more detailed overview of the electricity industry's regulatory bodies refer to Annex 6.

3.2.3 Power Generators

The South African electricity industry is dominated by the state-owned electricity utility Eskom. Eskom generates 95% of the country's electricity, with the remaining 5% generated by state municipalities and independent power producers (IPPs). Electricity is then supplied via Eskom's transmission lines unless the municipal generators or IPPs are within the municipality themselves or serve large local customers. Distribution lines are then used by the 177 municipalities (40%) and Eskom (60%) to deliver electricity to the final consumer (see Figure 14) (Eberhard, 2004).

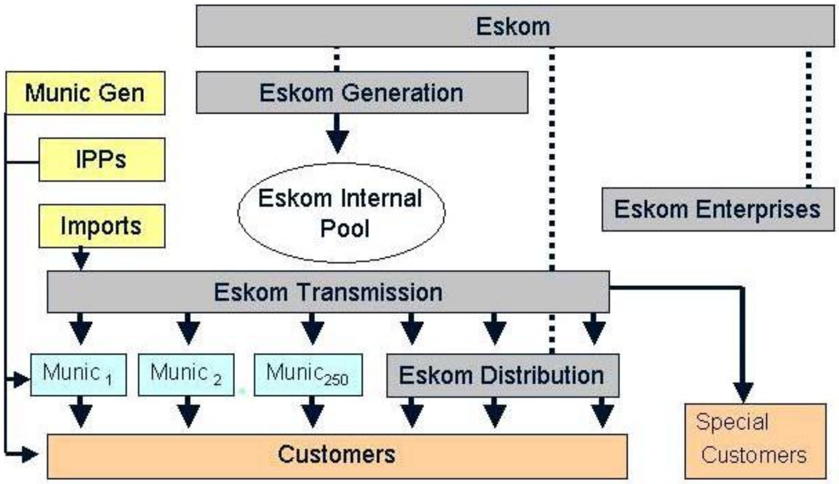


Figure 14: Existing electricity industry structure (Eberhard, 2004)

Eskom owns the entire transmission grid and part of the distribution grid, which have a frequency of 50 Hz (Eskom Website, 2009). Eskom's electricity generation is dominated by coal-fuelled production (88%), with minor use of hydro power (6%), nuclear (5%) and other renewable (1%) technologies. The coal plants are based in the North-East of the country near Johannesburg where both the primary coal mines and highest electricity demand are found (Spalding-Fletcher & Matibe, 2003).

Figure 15 below depicts Eskom's power plants and the national grid. The utility owns eleven large scale coal-fuelled plants and one nuclear plant which are its base load stations (Eskom Website, 2009). In addition, four open gas cycle turbines and four hydro powered plants account for peak load demand. The remaining plants are either mothballed (out-of-service) and under review for returning-to-service or are being used to stabilize distribution. Eskom owns 28,236 km of transmission power lines and 45,302 km of distribution power lines, while all power lines and cables (of all voltages) amount to 381,700 km (Eskom, 2009).

Figure 15: Eskom's transmission grid and power stations in South Africa (Eskom Website, 2009)

Municipalities and IPPs supply a mere 5% of South Africa's electricity. To increase IPP growth and thereby create a more balanced market for the supply of electricity, the 2003 South African Cabinet decided that future power generation capacity would be divided between Eskom (70%) and IPPs (30%) (Eskom Website, 2009). Following this decision, the 2007 South African Cabinet authorized Eskom to act as a single buyer and procure all the power that IPPs produce. This secured electricity sales for the IPPs as they were guaranteed the purchase of the power produced. It also eliminated the need for a contract between IPPs and end consumers. Nonetheless, IPP growth has been slow, demonstrating the need for further incentives.

For more detailed information on South Africa's electricity generators refer to Annex 6.

3.2.4 Industry Restructuring

Negotiations regarding the restructuring of the electricity industry have been underway since 1997 (Eberhard, 2004). The government was interested in redefining its relationship with Eskom to evaluate its monopolistic power in the electricity distribution industry. Eskom is state-owned, yet the company has no formal obligations to adhere to and was unable to provide almost a third of South Africans with electricity. A reform would encourage investment and accelerate the Black Economic Empowerment (BEE) process. This would be achieved by divesting generation assets to private owners thereby creating a competitive electricity industry structure and not simply creating another private monopoly.

In 1999 the Cabinet agreed that there should be six REDs which would be managed and implemented by a new publicly owned administrator, the Electricity Distribution Industry (EDI) Holdings (Eberhard, 2004). Each RED required the right balance of below-cost (low-income residential) and above-cost (commercial and industrial) users to equalize the markets. The intended RED boundaries are depicted in Figure 15 below.

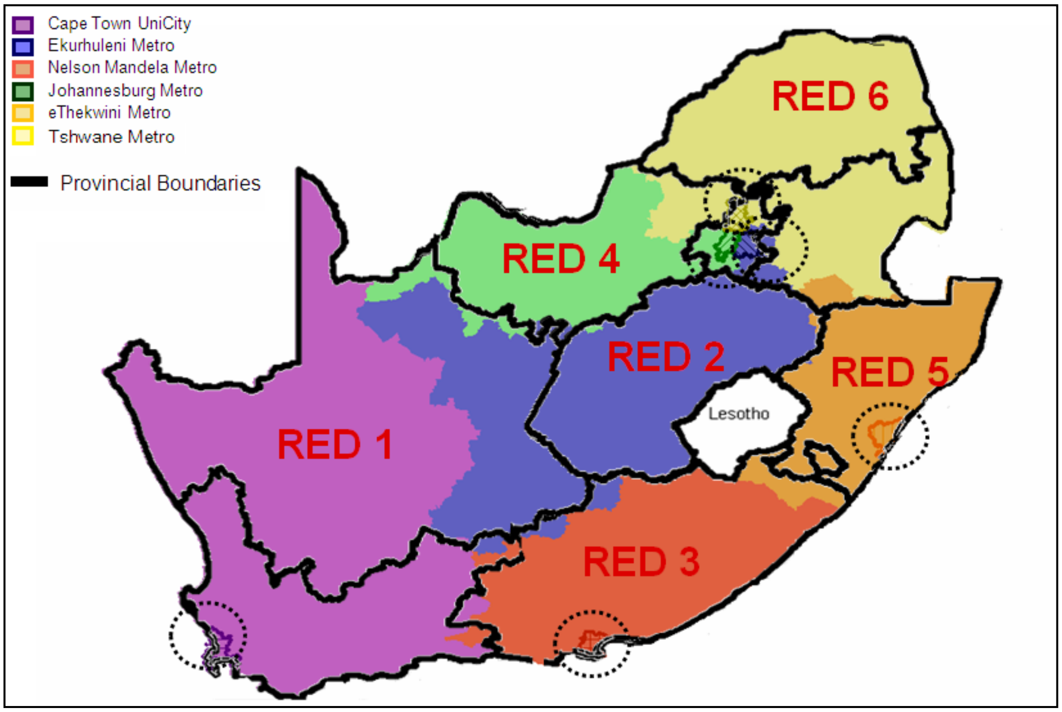


Figure 16: RED boundary map (EDI Holdings, 2009)

To date, the REDs have not been implemented and the reform is thought to be hindered by a power struggle in the political framework. The cabinet supports finding a national solution to the problems of electricity distribution, but local governments fear losing their influence (Eberhard, 2004). However, the industry is eventually expected to follow the RED framework as shown in Figure 176, even though the new model still presents potential problems. The reform will provide new entrants with greater confidence due to transparent market rules between the independent transmission company and power exchange.

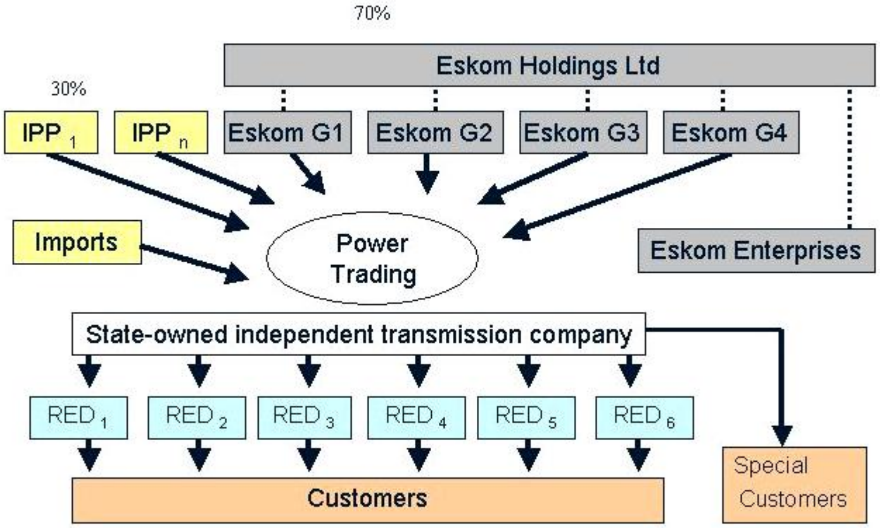


Figure 17: Eskom generation subsidiaries with open access and trading (Eberhard, 2004)

3.2.5 Electricity Cost

Historically, South Africa's electricity price was one of the lowest in the world due to its cheap production. This low-cost production was based primarily on the abundance of coal and relatively low labour costs (Energy Information Administration, 2008). However, in June 2009 the average electricity price increased by 31.3% from the previous year, resulting in the average standard tariff increasing from 25.24c/kWh to 33.14c/kWh (NERSA, 2009). This includes a 2c/kWh environmental levy on the sale of electricity generated from non-renewable sources.

Eskom has applied for further price increases amounting between 20% and 25% each year over the next three years to offset the increase in generation costs due to the building of new capacity

(Eskom Website, 2009). Figure 187 depicts electricity costs in ZAR/kWh using the annual price adjustment (as published by Eskom) to extrapolate the cost in 2000 and assuming that cost and sales price increase proportionately (Vestas, 2008). This shows that costs are expected to reach 22c/kWh in 2010, nearly doubling since 2000.

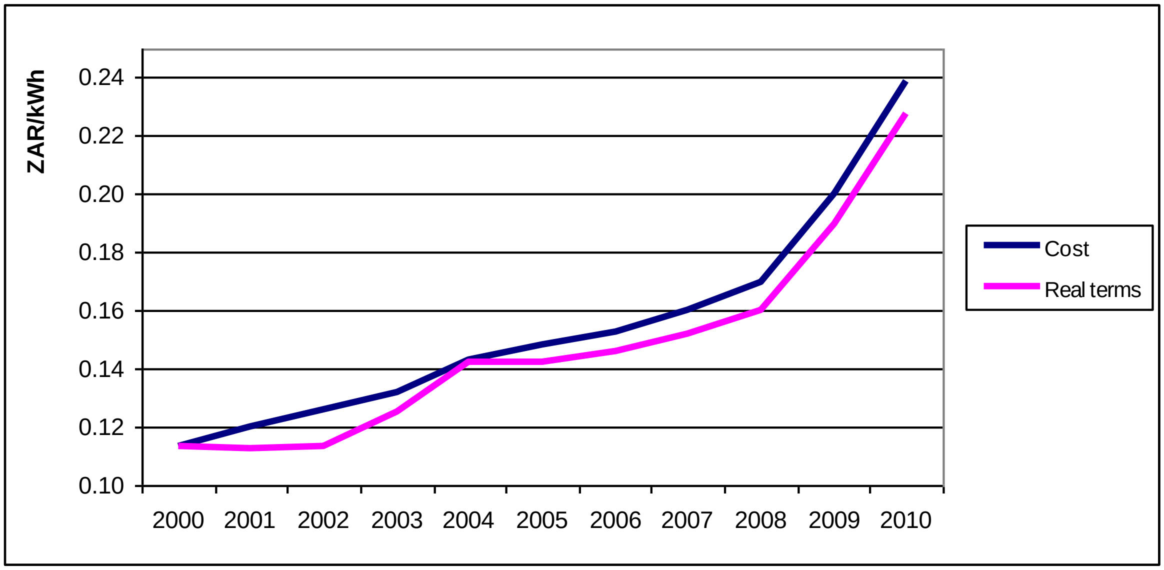


Figure 18: South African electricity cost (Vestas, 2008)

Furthermore, the recent introduction of feed-in tariffs for renewable energy will add to the electricity price. This feed-in tariff was approved in two phases over the course of 2009 and guarantees a price and purchase for grid-connected renewable energy producers. Eskom will account for the fossil-equivalent costs of new generating capacity; hence the utility will pay what 1 MW of capacity costs for fossil-based generating capacity even if the cost is greater for the new renewable power capacity. The difference in additional cost of this incentive for renewable capacity will be borne by all electricity consumers.

3.2.6 Renewable Energy

South Africa has plentiful renewable energy resources, yet traditional biomass (for example, wood fires) is the only large renewable energy contributor to national energy use (NERSA, 2009). It is also the cause of indoor pollution associated with respiratory health problems and unsustainable deforestation practices. The Regulator reported that the country exhibits:

> *'...abundant wind resources, amongst the highest levels of solar radiation in the world and excellent potential for the use of pulp and paper, bagasse [fibrous residue from sugarcane or sorghum] and other biomass bi-products...' (NERSA, 2009)*

To encourage their development, the 2003 White Paper on Renewable Energy (herein referred to as the White Paper) set a renewable energy target of 10,000 GWh or roughly 1.14 GW contribution to final energy consumption by 2013 (DME, 2003). To support this target, the renewable energy feed-in tariff (REFIT) was put in place in 2009 and provides a set price for sustainable technologies, namely wind, small hydro, landfill gas, solid biomass, biogas, photovoltaic systems and concentrated solar plants (NERSA, 2009).

South Africa would be subject to a number of socio-economic and environmental benefits in using electricity from renewable energy. These include increased energy security and stability, reducing transmission costs, resource saving (for example, water use in coal fired plants), pollution reduction, support for international agreements and enhanced status within the international community, employment creation, acceptability to society and growth of a new industry sector (Karottki, Schäffler, & Banks, 2001) (NERSA, 2009). The Capacity Building in Energy Efficiency and Renewable Energy (CaBEERE) project demonstrated these benefits. CaBEERE maintains that reaching the White Paper's 2013 target will increase government revenue by close to ZAR300 million and increase GDP up to ZAR1 billion, while creating roughly 20,500 new jobs and saving 16.5 billion litres of water (NERSA, 2009).

Chapter 4: Renewable Energy Drivers

4.1 Kyoto Protocol

South Africa ratified the United Nations Framework Convention on Climate Change (UNFCCC) in 1997 and the Kyoto Protocol in 2002 (DME, 2003). South Africa is among the non-Annex 1 countries which are considered to be developing as opposed to developed. Consequently, the country is not committed to a quantified emissions reduction target during the Kyoto period of 2008 through 2012.

South Africa is still able to benefit from this agreement as companies will receive international funds for developing renewable energy projects (DME, 2003). These international funds come in the form of the Global Environment Facility (GEF) and the Clean Development Mechanism (CDM). The GEF is an independent financial organization which provides grants to developing countries for projects related to the environment and climate change. The CDM specifically aims to reduce greenhouse gasses in developing countries while helping developed countries to reach their Kyoto Protocol commitment. That is, the CDM provides for the certified emission reductions between non-Annex 1 and Annex 1 countries. The Designated National Authority (DNA) oversees the CDM projects in South Africa and has thus far registered two non-wind related projects.

The United Nations Climate Change Conference held in Copenhagen in late 2009 aimed to set new binding targets for its members, yet no agreement was reached. The Copenhagen Accord was drafted by China, India, US, Brazil and South Africa and is essentially a continuation of the Kyoto Protocol (UNFCCC, 2009). However, this Accord is not legally binding and was merely agreed to be “taken note of”.

4.2 White Paper on Renewable Energy

In November 2003 the DME developed the White Paper on Renewable Energy (DME, 2003). In its White Paper, the DME summarized their ten year target as:

> *10,000 GWh (0.8 Mtoe) renewable energy contribution to final energy consumption by 2013, to be produced mainly from biomass, wind, solar and small-scale hydro. The renewable energy is to be utilised for power generation and non-electric technologies such as solar water heating and bio-fuels. This is approximately 4% (1,667 MW) of the projected electricity demand for 2013 (41,539 MW).*

The framework for meeting this ambitious target suggests that 60% be met by electric sources and 40% by non-electric sources (DME, 2004). Eskom is expected to supply 40% of the 6,000 GWh electric target, with IPPs meeting the remaining 60% of 3,600 GWh. The IPP portfolio will be achieved on a competitive bidding basis. It is expected to consist of biomass projects under the size of 1 MW, small scale hydro projects between 1 MW and 10 MW, and large wind projects of over 20 MW. The chosen IPP projects will receive a premium tariff in order to ensure the financial feasibility of the venture.

Though no target has been specifically set for wind power, the White Paper conservatively estimated that it could supply at least 1% of South Africa’s projected electricity requirements, which was roughly 1,980 GWh in 2002 (DME, 2003). This excluded offshore wind energy potential and was established before detailed wind speeds had been measured.

4.3 Renewable Energy Feed-in Tariff

REFIT aims to support the Government’s 10,000 GWh renewable energy target and deliver sustained long term growth in order to promote competitiveness for renewable energy with conventional energies (NERSA, 2009). REFIT guarantees that licensed renewable energy generators have access to the national grid and receive a premium price (that varies according to which renewable technology is utilized) for the power produced.

REFIT was presented by the Regulator in two phases during 2009 with each phase presenting the REFIT qualifying technologies and the respective approval documents listing the final outcomes. The first phase included wind, small hydro, landfill gas and concentrated solar plants with storage. The second phase added to the list concentrated solar plants with a tower, concentrated solar plants without storage, photovoltaics mounted on the ground or on buildings, biomass and biogas (NERSA, 2009).

Table 4: REFIT phase I and II tariffs (R/kWh) (NERSA, 2009)

Technology	REFIT (R/kWh)
Wind (on-shore)	1.250
Small hydro (less than 10 MW)	0.940
Landfill gas	0.900
Biomass (solid)	1.181
Biogas	0.962
Large-scale grid connected PV (larger than 1 MW)	3.940
Concentrated solar plant (with 6 hrs storage)	2.100
Concentrated solar plant (central tower with 6 hrs storage)	2.308
Concentrated solar plant (without storage)	3.132

The REFITs are presented in Table 44 above. The tariffs were calculated to cover the total cost of each renewable technology's generation and allow for a 'reasonable profit' to encourage investors (NERSA, 2009). The 20-year REFIT term is adjusted for inflation annually and may be modified or capped if there is oversubscription, though this only applies to new projects.

The power purchasing agency, REPA, will be operated by Eskom's Single Buyer Office (NERSA, 2009). Problems are foreseen in this regard, as Eskom itself will develop renewable energy projects and be eligible for the tariff that it regulates. REPA is required to enter into PPAs with renewable energy generators that have been awarded a license by the Regulator. REPA is also responsible for any wheeling charges (cost of transmitting electricity) while grid connection costs are borne by the generator. Renewable energy generators are also guaranteed access to the transmission and distribution networks provided that they meet the appropriate distribution and grid codes.

The interaction between the renewable energy power generator, REPA, the Regulator and the end consumer is presented in Figure 198.

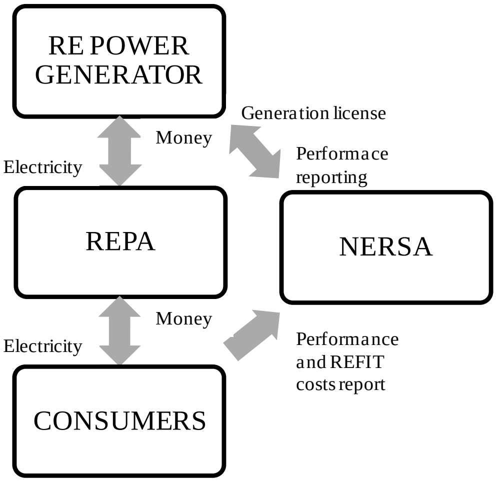


Figure 19: REFIT structure and process outline (NERSA, 2009)

Though generators may choose to sell their power to buyers other than REPA, this is not included in the tariff mechanism (NERSA, 2009). Other REFIT exceptions include cogeneration projects, off-grid generators (due to power measurement difficulties) and CDM projects. The latter entails that generators cannot benefit from both REFIT and CDM.

Further developments may include establishing REPA as separate entity as Eskom may apply for REFIT itself if it develops renewable energy and thereby would cause a conflict of interest. In addition, once the REDs have been established the REFIT terms could be revised such that they would also be allowed to purchase renewable energy power generation.

A more detailed summary on REFIT is presented in Annex 7.

Chapter 5: Conclusion

Due to the current state of the South African energy market and recent governmental efforts to improve it, wind energy has become a feasible option for power production in the country.

The strength and abundance of the national wind resource has been confirmed by a number of researchers. Their work shows that the most potential for exploiting wind power lies along the coast with a number of scattered inland regions. South Africa’s topography is also ideal for making use of the enhanced wind speeds at greater altitudes, as the mountainous escarpment runs within 240 km of the coast at any point. The well-developed grid also ensures that the distance between sites with favourable wind conditions and the local infrastructure need not be substantial. Additionally, the daily wind speed cycle tends to be in sync with the power demand cycle, thus aiding the electricity supply when it is needed most.

Having established the wind resource’s potential, the need for increased power generation was evaluated. South Africa’s reserve margin on its electricity generation capacity reached a dangerously low 8% in 2008, while forecasts show that electricity demand is set to increase steadily until at least 2035. New generation capacity in any form is encouraged by the government through incentives for independent power producers.

A concurrent issue is South Africa’s environmental impact. This is cause for concern due to the country’s high pollutant emission levels and water shortages. The 2003 White Paper aimed to limit this negative impact by setting renewable energy targets. The Regulator’s recently introduced feed-in tariff, REFIT, was developed to meet this target by encouraging the adoption of renewable energy projects. The tariff’s guaranteed electricity price for a number of qualifying sustainable technologies has resulted in certain renewable energy projects becoming economically feasible.

It is clear that South Africa is challenged with an electricity demand which cannot be met at the current generation capacity levels. The country also has favourable and unexploited wind power conditions; a resource which is both free and sustainable. The feed-in tariff, REFIT, has also rendered many wind power projects economically feasible. Hence, wind power has become a competitive and sustainable means to satisfying South Africa’s energy demands.

References

AWEA. (2009). *Principles.* Hentet November 12, 2009 fra American Wind Energy Association: http://www.awea.org/

Balachandran, N. R. (2009, November 4). Turbine to Substation Distances. (E. Micklem, Intervjuer)

Canadian Wind Energy Atlas. (2003). *Questions & Answers*. Hentet November 23, 2009 fra Canadian Wind Energy Atlas: http://www.windatlas.ca/en/faq.php

Danish Wind Industry Association. (2003, June 25). Hentet November 23, 2009 fra Danish Wind Industry Association: http://www.talentfactory.dk/en/tour/wres/enerwind.htm

Davenport, J. (2009, October 30). *Construction of R2,3bn Jeffreys Bay wind farm.* Hentet November 19, 2009 fra Engineering News: http://www.engineeringnews.co.za/article/construction-of-r23-bn-wind-farm-to-start-q1-2011-2009-10-30

Davenport, J. (2009, August 28). *Enviro study into R1,5bn Western Cape wind farm project to start next month.* Hentet November 19, 2009 fra Engineering News: http://www.engineeringnews.co.za/article/langefontein-wind-farm-2009-08-28

DEAT. (2000, July). *The shape of the provinces*. Hentet November 23, 2009 fra DEAT: http://www.deat.gov.za/Enviro-Info/prov/shape.htm

Department of Water Affairs and Forestry. (2003). *Water Conservation and Water Demand Managament Strategy for Industry, Mining and Commercial water use sector.* Pretoria: Department of Water Affairs and Forestry.

Diab, R. (1995). *Wind Atlas of South Africa.* Pretoria: Department od Mineral and Energy Affiars.

DME. (2005, June). Hentet September 20, 2009 fra Department for Minerals and Energy: http://www.dme.gov.za/pdfs/energy/240605_darling_wind_farm_approved_by_ho.pdf

DME. (2004). *Renewable Energy Framework.* Hentet September 20, 2009 fra DME: http://www.dme.gov.za/pdfs/energy/Renewable%20Energy%20Framework%20_2_.pdf

DME Website. (2009). Hentet October 26, 2009 fra Department of Minerals and Energy: http://www.dme.gov.za/

DME. (2003). *White Paper on Renewable Energy.* Pretoria: DME.

Eberhard, A. (2004). *The Political Economy of Power Sector.*

EDI Holdings. (2009). *EDI Holdings*. Hentet November 6, 2009 fra EDI Holdings: www.eskom.co.za

Energy Information Administration. (2008, October). *Country Analysis Briefs: South Africa.* Hentet November 3, 2009 fra Energy Information Administration: http://www.eia.doe.gov/emeu/cabs/South_Africa/pdf.pdf

Eskom . (2009). *Annual Report.*

Eskom. (2009). *Tariffs & Charges 2009/10.* Eskom.

Eskom Website. (2009). *Eskom Website*. Hentet September 22, 2009 fra Eskom Website: http://www.eskom.co.za/

Genesis Eco-Energy. (2009). *Genesis Eco-Energy*. Hentet November 16, 2009 fra Genesis Eco-Energy: http://www.genesis-eco.co.za/

Global Energy Decisions. (2006). *Stage 2 Report: Electricity Consumption and Demand Forecast for Development of Third National Integrated Resource Plan for South Africa.* Pretoria: NERSA.

Hagemann, K. (2009, November 16). Grid Infrastructure. (E. Micklem, Intervjuer)

Hagemann, K. (2009). *Mesoscale Wind Atlas of South Africa.* Cape Town: University of Cape Town.

Hansen, J. C., Jørgensen, H., Hahmann, A., & Mortensen, N. (2009). *Wind Mapping South Africa.* Pretoria: Risø DTU.

IEA. (2009). *CO2 emissions from fuel combustion highlights.* Paris: IEA.

Index Mundi. (2009). Hentet October 26, 2009 fra Index Mundi: http://www.indexmundi.com/south_africa/gdp_real_growth_rate.html

Jargstorf, B. (2004). *Wind Regimes of Africa: Comparative Evaluation of Wind Data from Selected Countries.* Factor for Energy Projects.

Karottki, R., Schäffler, J., & Banks, D. (2001). *Wind energy in South Africa - time to implement.*

Marquard, A., Bekker, B., Eberhard, A., & Gaunt, T. (2007). *South Africa's Electrification Programme.* Cape Town: Management Programme in Infrastructure Reform & Regulation.

UNFCCC. (2009). *Copenhagen Accord.* Copenhagen.

NERSA. (2009). *NERSA decision on renewable energy feed-in tariffs (REFITs) phase II.* Pretoria: NERSA.

NERSA. (2009, June 25). *NERSA's decicion on Eskom's application for an interim price increase.* Hentet November 16, 2009 fra Eskom : http://www.eskom.co.za/content/FinalmediaNERSA25Jun09.pdf

NERSA. (2009). *Renewable Energy Feed-In Tariff Phase 2.* Pretoria: NERSA.

NERSA. (2009). *South Africa Renewable Energy Feed-in Tariff (REFIT).* Pretoria: NERSA.

NERSA Website. (2009). Hentet October 4, 2009 fra National Energy Regulator of South Africa: http://www.nersa.org.za/

OWSC. (2009, November). Hentet November 23, 2009 fra OWSC: http://www.climate.washington.edu/climate.html

Routes. (2009). Hentet November 10, 2009 fra Routes: http://www.routes.co.za/weather/fs/bloemfontein.html

SABRE-Gen Energy. (2009). *South Africa Renewable Energy Resource Database*. Hentet November 12, 2009 fra http://www.sabregen.co.za: http://www.sabregen.co.za/sarerd%20database/sabregen-sarerd%20database.htm

SAPP. (2009). Hentet September 15, 2009 fra Southern African Power Pool: http://www.sapp.co.zw/index.cfm?siteid=1

Smit, I., van Heerden, L., & Smit, R. (2008). *Sharing Eskom's experiences in wind energy.* Eskom.

South Africa Info. (2009). *South Africa: Economy Overview.* Hentet October 26, 2009 fra South Africa Info: http://www.southafrica.info/business/economy/econoverview.htm

South African Government Information. (2008, January). *National Response To South Africa's Electricity Shortage.* Hentet November 15, 2009 fra South African Government Information: http://www.info.gov.za/otherdocs/2008/nationalresponse_sa_electricity1.pdf

Spalding-Fletcher, R., & Matibe, D. K. (2003). Electricity and externalities in South Africa. *Energy Policy* , 14.

Statistics South Africa. (2009, July). *Electricity generated and available for distribution.* Hentet October 4, 2009 fra Statistics South Africa: http://www.statssa.gov.za/publications/P4141/P4141July2009.pdf

Transparency International. (2008). *Corruption Perceptions Index.* Hentet November 14, 2009 fra Transparency International: http://www.transparency.org/news_room/in_focus/2008/cpi2008/cpi_2008_table

Tripod Wind Energy & Oelsner Group. (2003). *Baseline Study on Wind Energy in South Africa.* DME.

UNFCCC. (2009). *Copenhagen Accord.* Copenhagen.

Vestas. (2008). *Business Plan - South Africa 2008-2013.* Vestas.

WAsP. (2009). Hentet November 23, 2009 fra Wind Atlas Analysis and Application Programme: http://www.wasp.dk/

World Bank Group. (2009). *Doing Business 2010 South Africa.* Washington: The world Bank & International Finance Corporation.

WWEA. (2006, November 20). Hentet November 17, 2009 fra World Wind Energy Association: http://www.wwindea.org/home/index.php?option=com_content&task=view&id=161&Itemid=2

XE. (2009, November 26). Hentet November 26, 2009 fra XE: http://www.xe.com/ucc/convert.cgi?Amount=1&From=EUR&To=ZAR&x=23&y=10

Annex 1: Wind Resource Evaluation

Power in the Wind

A number of factors affect the quality of a country's wind resource which in turn affects a wind turbine's production. These include air density, wind speed and wind direction (AWEA, 2009). Many wind related factors are captured in the formula for the power in the wind (Watt), which is essentially the power output of a wind turbine:

$$\textit{power in the wind} = \tfrac{1}{2}\,\rho A V^3$$

where ρ is the air density (kg/m^3), A is the area which the turbine blades sweep (m^2) and V is the wind speed (m/s) (Smit, van Heerden, & Smit, 2008). A modern wind turbine typically has a conversion rate of wind power to power out of a turbine of 40%. According to Betz's law, the wind behind a turbine cannot be stationary and consequently the maximum conversion rate is roughly 60%.

Air Density

The power available in the wind is directly proportional to air density. That is, the 'heavier' the air the more power is received (Danish Wind Industry Association, 2003). Air density is determined by temperature, ambient air pressure and humidity (Smit, van Heerden, & Smit, 2008). A higher air temperature, air pressure and humidity level causes a lower air density. To form comparisons between power curves, data are presented under standard conditions in which temperature is usually 15 degrees Celsius and standard pressure depends on the regional system.

Wind Speed

Wind speed increases the turbine power output exponentially and is affected by factors such as seasonality and land topography. Wind varies from season to season and from year to year, necessitating long-term and high quality wind data in order to make any inferences (AWEA, 2009). Land topography includes elements such as elevation, roughness and obstacles (Hansen, Jørgensen, Hahmann, & Mortensen, 2009). Elevation generally exerts influence on wind flows such that a 5% increase in height could increase wind speeds by 5% and consequently increase power in the wind by a power of 3. The opposite effect could occur just below a hill. However, both temperature and pressure decrease with increasing altitudes resulting in trade off between air density and elevation that needs to be taken into account.

Most weather stations measure wind speeds at a 10m height while turbine hub heights are generally between 60 and 100m high (Hagemann, Mesoscale Wind Atlas of South Africa, 2009). The wind profile power law relationship is used to extrapolate wind speeds:

$$V/V_r = (z/z_r)^{\alpha}$$

where V is the wind speed (m/s) at height z (m), and V_r is the known wind speed at a reference height z_r (10m for the example mentioned above) (WAsP, 2009). The exponent α is an empirically derived coefficient that varies depending upon atmospheric stability. In the case of neutral stability, α is approximately 1/7, or 0.143. However, applying formulas to complicated terrains can lead to inaccurate results; a problem easily solved by using a numerical model based on the wind measurements at specific locations. The Wind Atlas Analysis and Application Programme (WAsP) is an example of such a model and has been developed and distributed by the Wind Energy Department at Risø National Laboratory in Denmark.

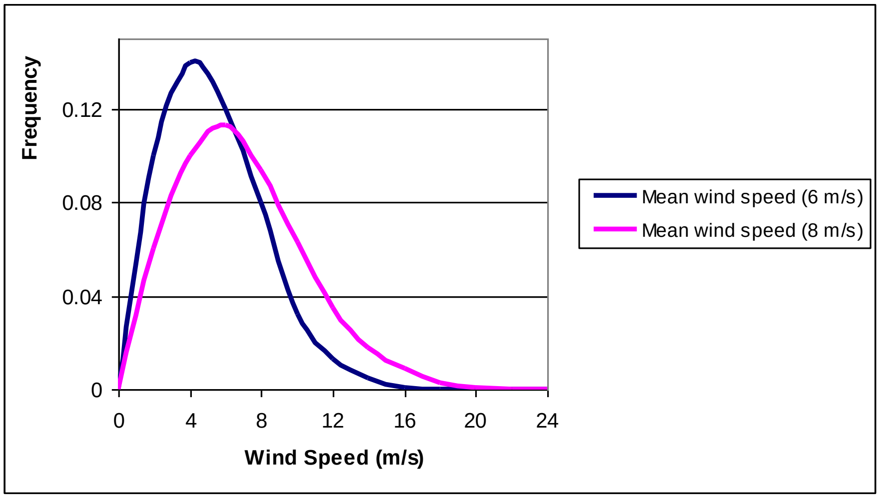
Wind speed is categorized in different classes according to the table below. The American Wind Power Association (AWEA, 2009) suggests that annual wind power classes of at least 3 are required for grid-connected applications, while a wind power class of 5 or more is ideal.

Wind power classes (AWEA, 2009)

Wind power class	10 m		50 m	
	Wind power density (W/m^2)	Speed (m/s)	Wind power density (W/m^2)	Speed (m/s)
1	<100	<4.4	<200	<5.6
2	100 - 150	4.4/5.1	200 - 300	5.6/6.4
3	150 - 200	5.1/5.6	300 - 400	6.4/7.0
4	200 - 250	5.6/6.0	400 - 500	7.0/7.5
5	250 - 300	6.0/6.4	500 - 600	7.5/8.0
6	300 - 400	6.4/7.0	600 - 800	8.0/8.8
7	>400	>7.0	>800	>8.8

Note: Vertical extrapolation of wind speed based on the 1/7 power law

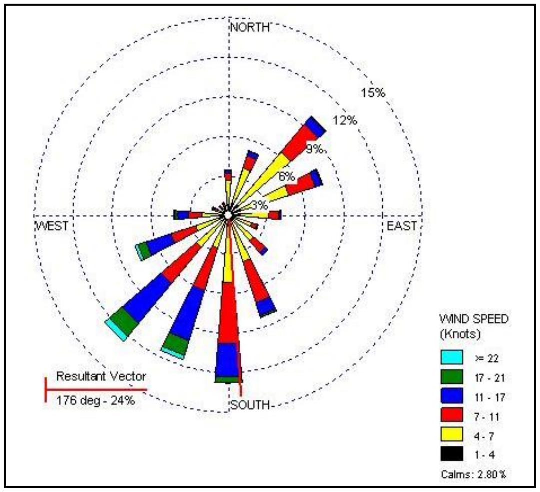
Identifying a location's wind class merely provides a basis for conducting further analysis, as it is the duration that different wind speeds occur which determines wind power potential. Accordingly, wind speed is often reproduced in terms of the Weibull distribution parameters (AWEA, 2009). A Weibull distribution generally determines the most efficient wind turbine type based on optimal cut-in and cut-out speeds. Weibull parameters are given as the average wind speed *V* (m/s) and the shape *k*, which takes on a value between 1 and 3. A shape value of 2 indicates a location with a large amount of low wind speeds and a few very high wind speeds, while a shape of 3 indicates consistent wind speeds around the median value. The Canadian Wind Energy Atlas (2003) depicts this difference in the figure below, where the blue line has a lower shape value than the red line.



Example of a Weibull distribution (Canadian Wind Energy Atlas, 2003)

Wind Direction

Although wind direction has no role in the above equations, a highly fluctuating wind direction can render a wind turbine useless. The majority of wind turbines rotate to face the direction of the wind, though this rotation causes inefficiency and is therefore avoided. The figure below**Error! Reference source not found.** illustrates the duration that wind comes from each direction with the length of each spoke, while the colours represent the wind speed.



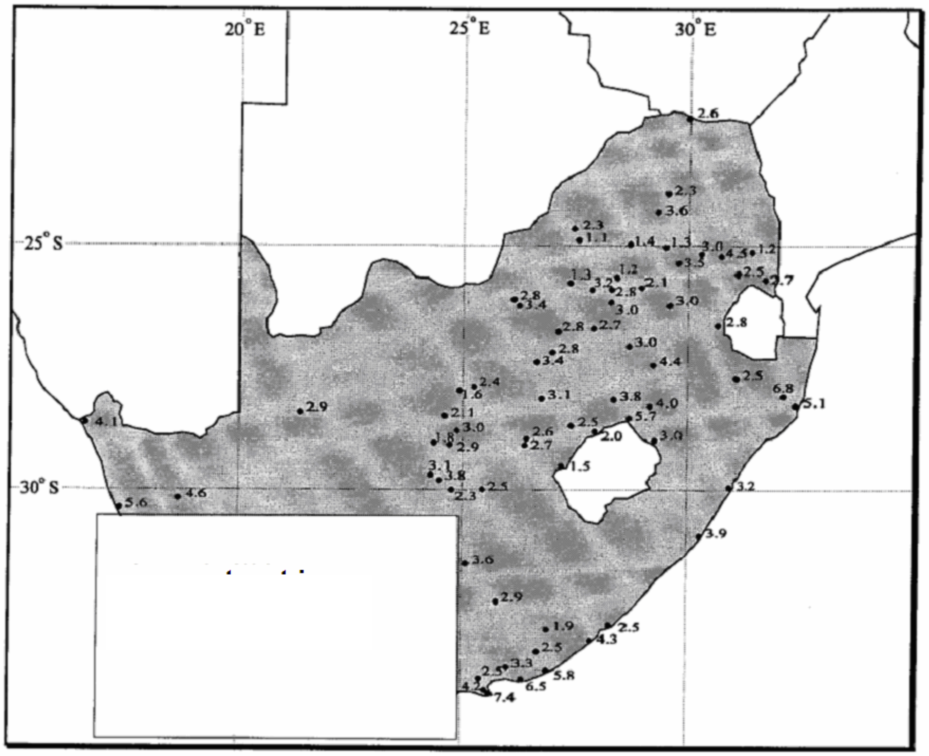
Example of wind rose (OWSC, 2009)

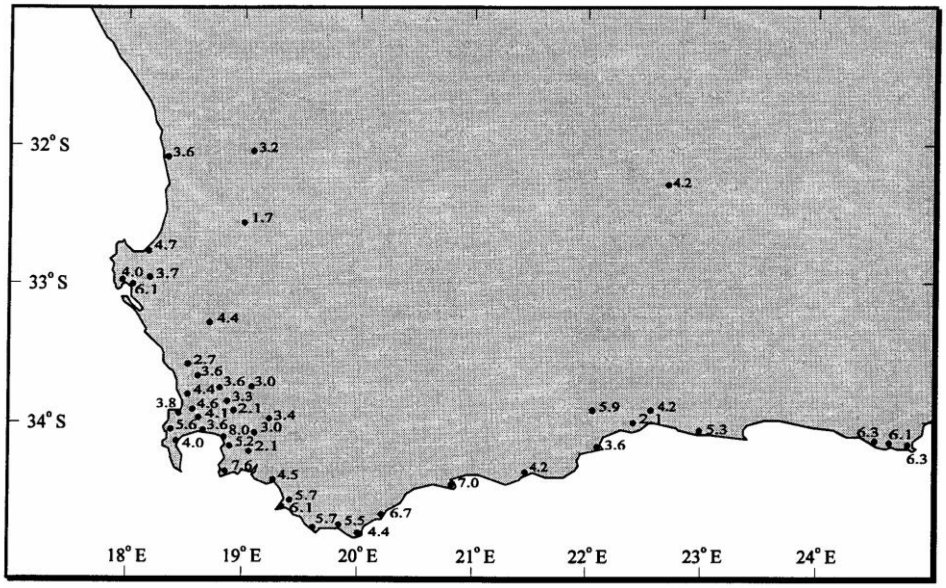
Availability and Capacity Factors

Once a turbine has been installed, its availability and capacity factor are measures for determining its power production levels. The availability of a turbine refers to the amount of time it is able to generate power (that is, not under maintenance or construction) and is normally near 95%. The capacity factor is the amount of power the turbine produces as a percentage of the power that would have been produced if the turbine operated at maximum output 100% of the time (AWEA, 2009).

> *Although modern utility-scale wind turbines typically operate 65% to 90% of the time, they often run at less than full capacity. Therefore, a capacity factor of 25% to 40% is common, although they may achieve higher capacity factors during windy weeks or months. (AWEA, 2009)*

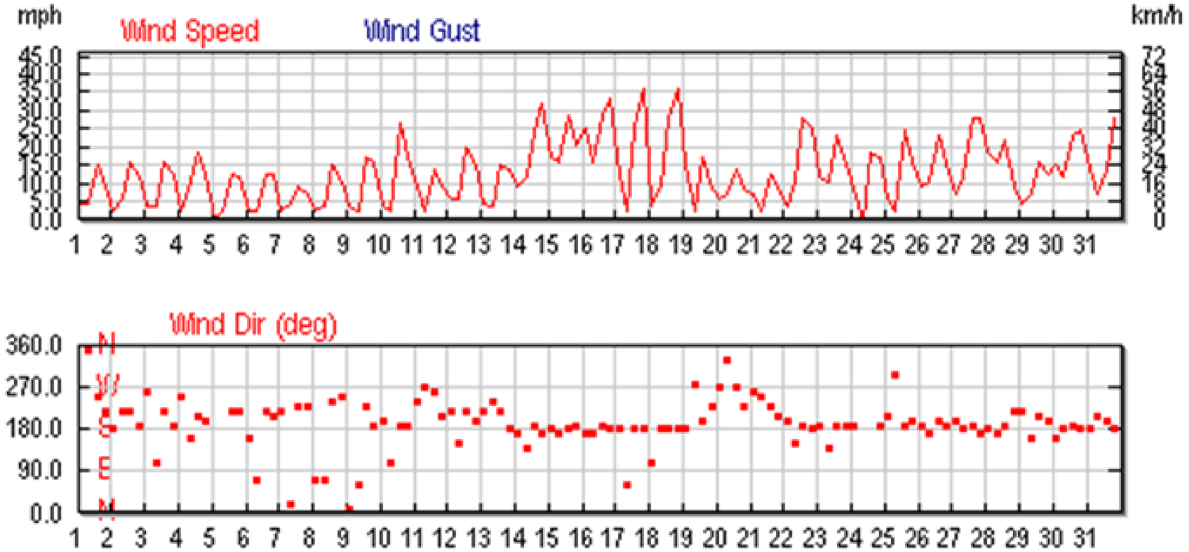
Annex 2: Meteorological Stations' Annual Wind Speeds (m/s)



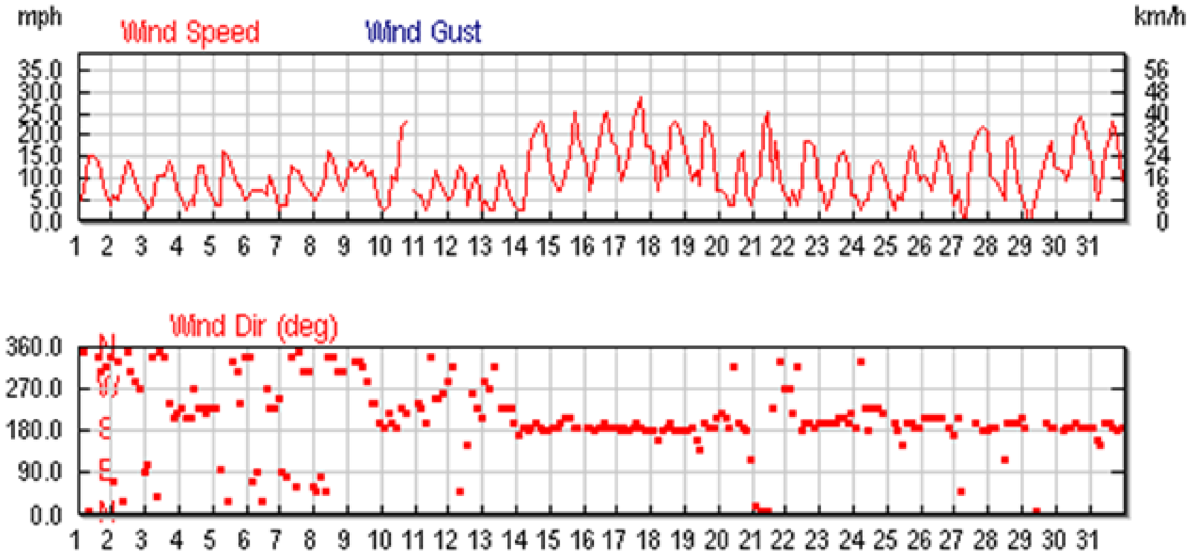


(Jargstorf, 2004)

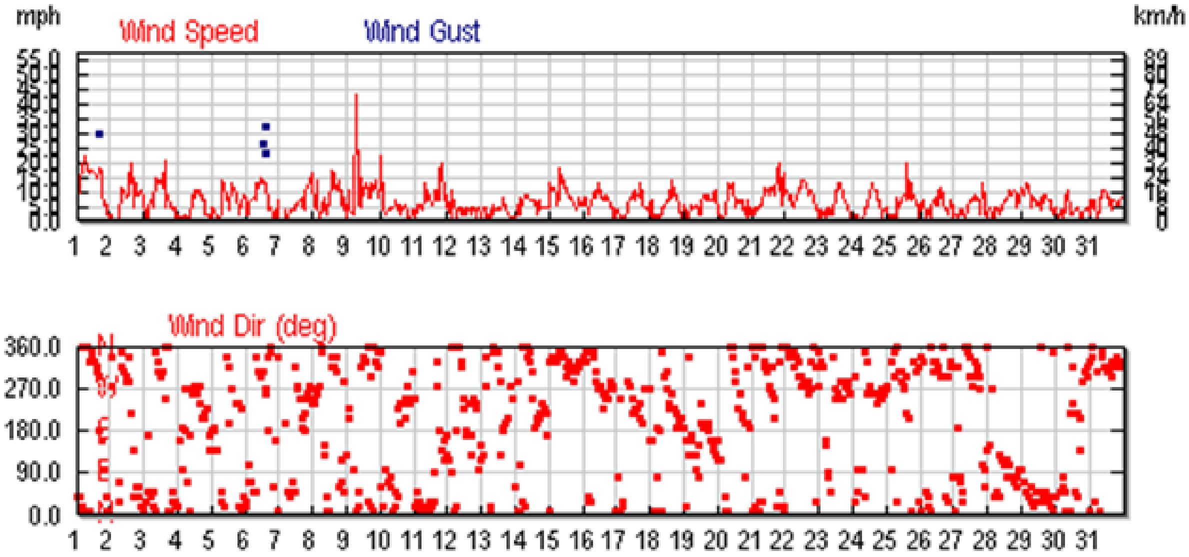
Annex 3: Monthly Wind Speeds and Directions (Two Locations and Two Seasons)



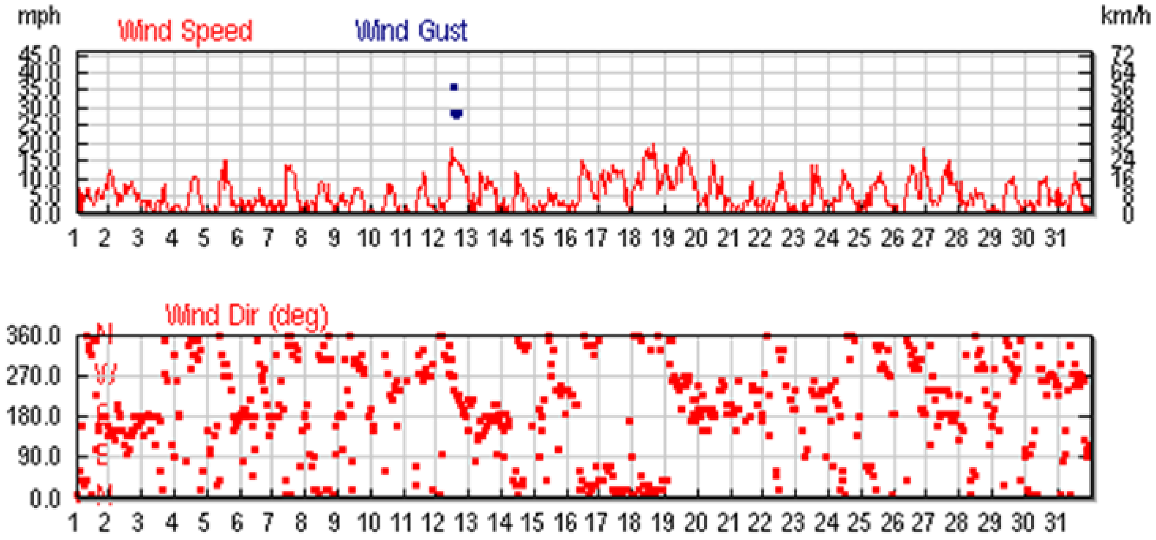
Alexander Bay: Wind speeds in January 2009 (average of 17 km/h or 4.7 m/s)



Alexander Bay: Wind speeds in August 2009 (average of 10 km/h or 2.8 m/s)

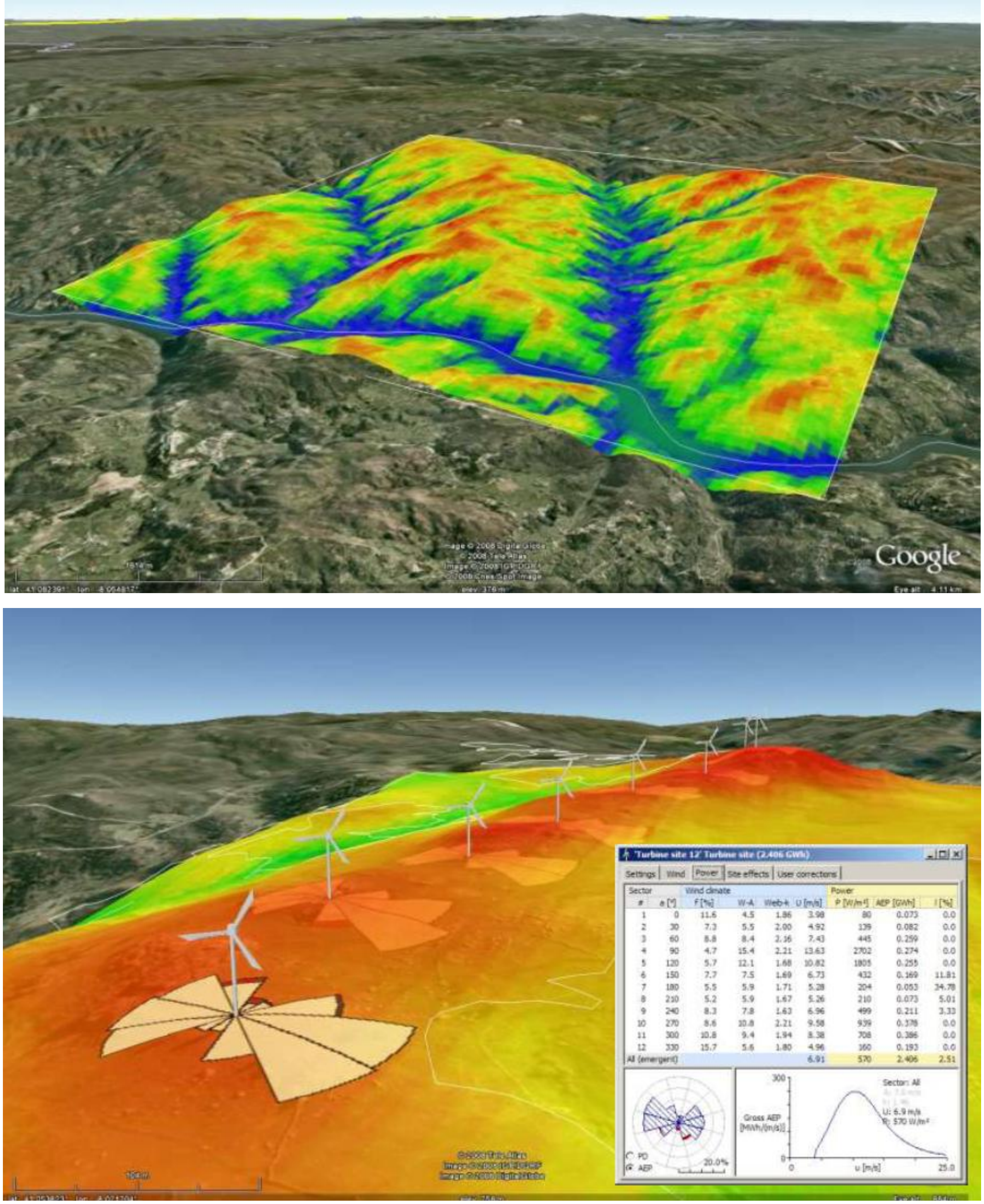


Bloemfontein: Wind speeds in January 2009 (average of 12 km/h or 3.3 m/s)



Bloemfontein: Wind speeds in August 2009 (average of 6 km/h or 1.7 m/s)

Annex 4: Example of WAsP Output



Sector		Wind climate				Power		
#	a [°]	f [%]	W-A	Weib-k	U [m/s]	P [W/m²]	AEP [GWh]	I [%]
1	0	11.6	4.5	1.86	3.98	80	0.073	0.0
2	30	7.3	5.5	2.00	4.92	139	0.082	0.0
3	60	8.8	8.4	2.16	7.43	445	0.259	0.0
4	90	4.7	15.4	2.21	13.63	2702	0.274	0.0
5	120	5.7	12.1	1.68	10.82	1805	0.255	0.0
6	150	7.7	7.5	1.69	6.73	432	0.169	11.81
7	180	5.5	5.9	1.71	5.28	204	0.053	34.78
8	210	5.2	5.9	1.67	5.26	210	0.073	5.01
9	240	8.3	7.8	1.63	6.96	499	0.211	3.33
10	270	8.6	10.8	2.21	9.58	939	0.378	0.0
11	300	10.8	9.4	1.94	8.38	708	0.386	0.0
12	330	15.7	5.6	1.80	4.96	160	0.193	0.0
All (emergent)					6.91	570	2.406	2.51

(Hansen, Jørgensen, Hahmann, & Mortensen, 2009)

Annex 5: Business Development Indicators

Starting a Business	Procedures (number)	6
	Time (days)	22
	Cost (% of income per capita)	5.9
	Min. capital (% of income per capita)	0
Dealing with Construction Permits	Procedures (number)	17
	Time (days)	174
	Cost (% of income per capita)	24.5
Employing Workers	Difficulty of hiring index (0-100)	56
	Rigidity of hours index (0-100)	20
	Difficulty of redundancy index (0-10)	30
	Rigidity of employment index (0-100)	35
	Redundancy costs (weeks of salary)	24
Registering Property	Procedures (number)	6
	Time (days)	24
	Cost (% of property value)	8.7
Getting Credit	Strength of legal rights index (0-10)	9
	Depth of credit information index (0-6)	6
	Public registry coverage (% of adults)	0
	Private bureau coverage (% of adults)	54.7
Protecting Investors	Extent of disclosure index (0-10)	8
	Extent of director liability index (0-10)	8
	Ease of shareholder suits index (0-10)	8
	Strength of investor protection index (0-10)	8
Paying Taxes	Payments (number per year)	9
	Time (hours per year)	200
	Profit tax (%)	24.5
	Labour tax and contributions (%)	2.4
	Other taxes (%)	3.3
	Total tax rate (% profit)	30.2
Trading Across Borders	Documents to export (number)	8
	Time to export (days)	30
	Cost to export (US$ per container)	1531
	Documents to import (number)	9
	Time to import (days)	35
	Cost to import (US$ per container)	1807
Enforcing Contracts	Procedures (number)	30
	Time (days)	600
	Cost (% of claim)	33.2
Closing a Business	Recovery rate (cents on the dollar)	32.2
	Time (years)	2
	Cost (% of estate)	18

(World Bank Group, 2009)

Annex 6: Market Participants

The market participants involved in the wind power industry in South Africa are divided into regulatory bodies and power generators.

Regulatory Bodies

Department of Minerals and Energy

The DME is primarily responsible for ensuring that the White Paper's targets are met by 2013. The DME ensures the optimal utilization and safe exploitation of mineral and energy resources (DME Website, 2009). Among other responsibilities, the DME manages the electricity sector and regulates and promotes hydrocarbon energy carriers, and ensures integrated energy planning through policy development for the environment, renewable technology and the provision of administrative services.

In order to develop, formulate and implement strategies and legislation promoting energy efficiency and renewable energy, the DME and Denmark founded the Capacity Building in Energy Efficiency and Renewable Energy (CaBEERE) project. This project came to an end in 2005 though it provided the information on which the incentives for renewable energy are based.

Electricity Distribution Industry Holdings

In 2003 EDI Holdings was created to execute the DMEs strategy for the electricity industry's restructuring as specified by the 1998 White Paper on Energy Policy (EDI Holdings, 2009). The company will plan, implement and manage the creation of six financially viable REDs which span beyond provincial boundaries as illustrated by the figure below**Error! Reference source not found.**. The EDI Holding's objectives are to meet the country's electrification targets, operate in a financially sound and efficient manner and to provide low cost, reliable electricity to all consumers.

National Electricity Regulator of South Africa

The Regulator receives its authorization to oversee the electricity supply industry from the National Energy Regulator Act (Act No. 40 of 2004) (NERSA Website, 2009). The Regulator's mandate is electricity regulation, gas regulation and petroleum pipelines regulation in South Africa. The Regulator obtains its revenues by prescribing levies on the industries it regulates.

The Regulator aims to reduce the monopoly in the energy sector, improve competition and boost economic growth (NERSA Website, 2009). To achieve this goal in the electricity sector, the Regulator developed the renewable energy tariff called REFIT. The Regulator is the authority of REFIT and is permitted to set capacity limits on certain technologies to prevent over subscription. It has also appointed a separate entity, REPA, to implement the incentive (NERSA, 2009).

Renewable Energy Purchasing Agency

Eskom's Single Buyer Office manages the task of purchasing all IPP production (Eskom Website, 2009). This office was further mandated to take on the role of REPA for the sole reason of simplicity (NERSA, 2009). Thus, REPA is essentially a branch of Eskom which is responsible for purchasing the power generated by licensed IPPs at the rate stipulated by the REFIT. REPA also monitors and verifies all licensed renewable energy power producers (NERSA, 2009).

Power Generators

Eskom

The publicly owned Electricity Supply Commission (Eskom) was established in 1923 by mandate of the government's Electricity Act (1922) (Eskom Website, 2009). The utility has a generation, transmission and distribution division. The utility supplies 95% of the demanded electricity in South Africa, rendering the company the largest electricity producer in Africa. Eskom sells most of its electricity by bulk to large mining and industrial customers, and municipalities. In 2004, 89% of Eskom's electricity sales were accounted for by these three customer groups (Eberhard, 2004).

Eskom also imports and exports roughly 3% of its power combined to its neighbouring countries via the Southern African Power Pool (SAPP). SAPP was developed under the Southern African Development Community (SADC) in 1995 (SAPP, 2009) (Eberhard, 2004). This common market with other countries that have a shortage in electricity supply reveals the potential for future capacity developments. The SAPP member countries and their respective utilities as well as an illustration of how they are interconnected across Southern Africa are presented below.

SAPP member countries and respective electricity utilities (SAPP, 2009)

Country	**Electricity Utility**
Angola	Empresa National de Electricidade
Botswana	Botswana Power Co-operation
Democratic Republic of Congo	Societe National d' Electricite
Lesotho	Lesotho Electricity Corporation
Malawi	Electricity Supply Commission of Malawi
Mozambique	Electricidade de Mozambique, HCB, Motraco
Namibia	Nam Power
South Africa	Eskom
Swaziland	Swaziland Electricity Board
Tanzania	Tanzania Electric Supply Company
Zambia	Zambia Electricity Supply Corporation
Zimbabwe	Zimbabwe Electricity Supply Authority


EQUATORIAL GUINEA
GABON
CONGO
DEMOCRATIC REPUBLIC OF CONGO
UGANDA
KENYA
RWANDA
BURUNDI
CABINDA
Kinshasa
Inga
Owen Falls
Nairobi
Musoma
Mwanza
Arusha
Mombasa
Tabora
Singida
Dodoma
Hale
Pangani
Ubungo
132 kV cable to Zanzibar
Iringa
Dar Es Salaam
Kidatu
Kihansi
Songo Songo Gas Fields
TANZANIA
Luanda
Cambambe
Capanda
Lubaum
ANGOLA
Matala
Nseke and Nzilo
Hwadinguia and Koni
Likasi
Kitwe
MALAWI
MOZAMBIQUE
Lichinga
Cuamba
Alto Malema
Pemba
Nacala
Nampula
Alto Molocue
ZAMBIA
Lusaka
Kafue Lower
Kafue
Kariba S and N
Cahora Bassa
Mepanda Uncua
Tedzani
Kapichira
Ruacana
Epupa
Victoria Falls
Batoka
Gokwe N
Harare
Hwange
ZIMBABWE
Dala
Chicamba
Mavuzi
Beira
Bulawayo
NAMIBIA
Windhoek
Walvis Bay
BOTSWANA
Serule
Morupule
Makhado
Pande Gas Fields
Temane Gas Fields
Massingir
Inhambane
Matimba
Gaborone
Corumana
Pretoria
Xai-Xai
Maputo
Arnot
Johannesburg
Edwaleni II
SWAZILAND
ATLANTIC OCEAN
Lüderitz
Kudu CCGT
Drakensberg
Kimberley
Bloemfontein
Richards Bay
LESOTHO
Muela
Vanderkloof
Durban
INDIAN OCEAN
SOUTH AFRICA
Gariep
First Falls
Second Falls
Colley Wobbles
Ncora
East London
Port Rex
Not to scale
Koeberg
Acacia
Cape Town
Palmiet
Mossel Bay
Port Elizabeth
Key
Existing grid system
Possible future grid system
Hydroelectric power station
Thermal power station
Nuclear power station
Future hydroelectric power station
Future thermal power station
Interconnection substation
Future interconnection substation
Town

(Eskom, 2009)

South African Bulk Renewable Energy Generation

Eskom's past and present carbon emissions and water consumption is substantial (DME, 2003). The company's 2009 environmental report stated that it emits 221.7 million tonnes of CO_2 and consumes 323 billion litres of water per annum (Eskom, 2009). Thus, one kWh of electricity emits 1.03 kg of CO_2 and uses 1.5 litres of water on average.

In an effort to alter the company's negative impact on the environment, Eskom initiated the South African Bulk Renewable Energy Generation (SABRE-Gen) programme in 1998. SABRE-Gen evaluates the feasibility of large, renewable, grid-connected systems under Eskom's business operations. The aim of the programme is to determine whether these systems could provide viable solutions to South Africa's future electricity needs. SABRE-Gen's four components are bioenergy, wave power, concentrating solar power and wind, of which the latter two are in the implementation phases. SABRE-Gen has been responsible for evaluating the success of the Klipheuwel Wind Farm.

Klipheuwel Wind Turbine Test Facility

In late 2002 and early 2003, Eskom developed a small and experimental wind farm of three turbines on the West Coast near Cape Town (SABRE-Gen Energy, 2009). The 660 kW and 1750 kW turbines from Vestas (with installation by both Vestas and Vanguard) and the 750 kW turbine from Jeumont (installation by Jeumont and Summit Projects) amounted to a 3.2 MW wind farm.

These turbines have a typical cut in speed of around 3 to 4 m/s and a capacity factor of roughly 20% due to the variability in wind at Kliphuewel (EDI Holdings, 2009).

Koekenaap Wind Farm

Eskom is in the development phase of constructing a 100 MW wind farm just north of Cape Town on the West Coast (Eskom, 2009). Eskom signed a financing agreement of ZAR1 125 million over a twenty-year period with the French development agency Agence Française de

Dèveloppement (AFD) for partial funding of the project. Both Suzlon and Vestas have put in bids for supplying approximately 50 turbines (Vestas, 2008).

Municipalities

Municipalities are a division of the government below the provincial level. Each municipality is responsible for supplying its customers with electricity. Hence, power is usually purchased in bulk from Eskom and then distributed locally to customers. There are ten South African municipalities with power generating capabilities of their own, either through self-owned plants or IPP plants. The table below displays the power plants under both forms of ownership in each power generating municipality.

Power stations and total capacity in each municipality (Global Energy Decisions, 2006)

Municipality	Power Stations	Capacity (MW)
Greater Johannesburg Electricity Department / City Power	Kelvin IPP City Power Gas Turbines	776
Pretoria Electricity Department	Rooiwal IPP Pretoria West Power Station IPP	344
Cape Town Electricity Department	Steenbras Power Station Athlone Coal Plant IPP Roggebaai Gas Turbine	260
Bloemfontein/Mangaung	Centelec	105
Port Elizabeth Electricity Department	Gas Turbine	40
Durban Electricity Department	Mondi Merebank Cogeneration IPP under construction	
Lydenburg Electricity Department	Minor generating capacity	
Richards Bay Electricity	Rainbow Millenium IPP under construction	
Sabie Electricity Department	Minor generating capacity	
Uitenhage Electricity Supply Co. (Pty) Ltd	Minor generating capacity	

Independent Power Producers

IPPs require a Regulator certified license. This is achieved by demonstrating the plants’ financial viability with a Power Purchase Agreement (PPA) signed by the party who will be buying the power (NERSA Website, 2009). This is followed by negotiating a connection agreement with the owner of the network to which the plant will be connected, whether it be at transmission or distribution voltage levels.

Even though the single buyer agreement carried out by Eskom simplified the selling process, IPP growth is still slow (Eskom Website, 2009). The reason for the lack of growth remained the inexpensive price of coal rendering new projects, especially those in the renewable sector, uncompetitive. The introduction of REFIT in 2009 has altered this condition and numerous renewable IPPs are being reviewed. The IPP wind projects are outlined below.

Darling Independent Power Producer

The Darling IPP was established in 1997 by the Oelsner Group with technical support from German AN Windenergie GmbH and Danish Bonus Energy, both of which have now been acquired by Siemens (DME Website, 2009). Financial assistance was provided by the Danish Development Agency (Danida), the Central Energy Fund, and the Development Bank of South Africa, while the demand was accounted for by a 20-year PPA with the Cape Town municipality (DME, 2005).

The wind farm consists of ten 1.3 MW turbines to be installed in two phases located along the West Coast near Cape Town. After Siemens (Bonus Energy) failed to supply their turbines punctually, a new contract was awarded to Fuhrländer (WWEA, 2006). The first four turbines, amounting to 5.2 MW, were installed in late 2007 while phase 2’s construction has not yet commenced. The South Africa Wind Energy Programme (SAWEP) will provide further technical and financial assistance during phase 2 (DME Website, 2009).

Langefontein Wind Farm

The Oelsner Group has also won the tender to develop a wind farm on the state-owned Langefontein property in 2004 (Davenport, Enviro study into R1,5bn Western Cape wind farm project to start next month, 2009). Langefontein is situated near the Darling IPP and is subject to wind speeds of 6 m/s and higher. The project will be funded for ZAR1.5 million by an undisclosed European utility in order to offset its carbon emissions.

The project is still in the initial phases of an environmental impact assessment. Once this is completed, the 70 MW wind farm is expected to be built with the installation of twenty-eight 2.5

MW turbines (Davenport, 2009). The turbine procurement has been finalized through an agreement with an unrevealed France-based wind turbine manufacturer. The only France-based manufacturers are Vergnet, Alstom (through its subsidiary Ecotècnia) and Areva; however, none of these groups presently offers a 2.5 MW turbine.

Jeffreys Bay Wind Farm

Mainstream Renewable Power South Africa recently agreed to develop a wind power project on the South Coast close to Port Elizabeth (Davenport, 2009). The project is run by a joint venture between Cape Town-based Genesis Eco-Energy and Irish partner Mainstream Renewable Power. The estimated total investment of ZAR2.3 billion is still being procured, while the group itself has devoted ZAR800 million for the development phase.

The 125 MW wind farm is expected to begin construction of phase 1 in early 2011, following the approval of the environmental impact assessment (Davenport, 2009). Phase 1 will be the installation of 16 MW on a dairy farm and will consist of between 2 and 2.5 MW turbines on a dairy farm. These turbines will be procured from established vendors such as General Electric, Siemens and Vestas.

Other Projects under Consideration

Numerous other South African wind projects are undergoing negotiations. The West Coast-based St Helena Bay Wind Farm of 80 MW and a ZAR850 million investment is being planned by energy system developer, Genesis Eco-Energy. Genesis Eco-Energy is also evaluating a potential South Coast site of Walker Bay for a wind farm of 65MW. The Belgian wind farm developer, Electrawinds, and the Coega Development Corporation in South Africa are also evaluating the ZAR1.2 billion Coega Wind Farm Project. Twenty-five wind turbines of 2.3 MW each are being proposed for the South Coast site.

Annex 7: REFIT Guideline Summary

In 2007 the Regulator commissioned the study of the Renewable Energy Feed-In Tariff (REFIT) to support the country's energy target. The REFIT Phase 1 guidelines were released on 16 March 2009 and included the following key aspects:

Price

The FIT's are based on the levelised cost of electricity which take all of the electricity-generating costs over the lifetime of a project into account and net the present value to zero. Hence, the levelised cost of electricity is the minimum price at which the electricity should be sold for the project to break-even and is denoted in Rand per kilo Watt hour (R/kWh).

The 20 year REFIT term is adjusted for inflation annually. A review of the tariff will take place every year for the first five years of REFIT's implementation and once every three years thereafter; however, changes are only applied to new projects. Following REFIT's completion, the generator will be required to renegotiate its tariffs.

Purchasing

The Eskom Single Buyer Office was appointed as the Renewable Energy Purchasing Agency (REPA). REPA is required to enter into a Power Purchase Agreement (PPA) with renewable energy generators that have been awarded a license by the Regulator. REPA is also responsible for any wheeling charges.

Renewable energy generators are able to sell their power directly to buyers other than REPA, however, this is not within the REFIT mechanism and a license is still required. REFIT is only applied to power from generators connected to the transmission system and distribution system, while it excludes off-grid generators.

License conditions for renewable energy generators include

i. Reporting requirements on the amount of renewable energy generated and non-renewable energy;

ii. Monitoring and verification to ensure credible production of renewable energy

iii. Termination conditions for non-compliance on the production of renewable energy.

The Regulator is the authority that verifies the electricity production from renewable energy, though REPA carries out the plant inspections. The Regulator is also permitted to set capacity limits on certain technologies to prevent over subscription.

Eskom is responsible for ensuring that adequate generation capacity is made available to consumers and that 30% of the new power generation capacity is derived from IPPs. However, Eskom’s obligations are still being developed in terms of whether Eskom is only obliged to buy power from IPPs or whether it has the right to be the single buyer, limiting sales to buyers in the green market.

Further developments may also include establishing REPA as separate entity as Eskom may apply for REFIT itself if it develops renewable energy and thereby would cause a conflict of interest. In addition, once the REDs have been established the REFIT terms could be revised such that they would also be allowed to purchase renewable energy power generation.

Grid Access

Renewable energy generators are guaranteed access to the transmission and distribution networks providing that the provisions of the South African Distribution Code and the South African Grid Code are met respectively. The cost of connecting to the grid is borne by the generator.

Cost

The avoided cost is the marginal cost of energy for the same amount of energy achieved via other means. For example, when a renewable energy project is being implemented, the cost that would be avoided could be the expansion of a fossil-fuelled plant. The difference between the REFIT and the avoided cost is borne by all Eskom electricity customers through existing ‘pass-through’ arrangements.

REFIT Phase 2 was released in July 2009 and included an extended list of REFIT qualifying technologies.

The qualifying technologies along with their REFIT rates are set out below. Note that these appeared in the REFIT Phase 1 and Phase 2 Guidelines, though changes were made in the Phase 2 decision document made on 2nd November 2009. These changes included the exclusion on concentrating photovoltaic and the tariff was reduced for photovoltaic systems.

PARAMETER	UNITS	Wind	Small hydro	Landfill gas	Concentrated solar plant (with 6 hrs storage)	Concentrated solar plant (without storage)	Photovoltaic systems (ground/building-mounted > 1MW)	Biomass (solid)	Biogas	Concentrating photovoltaic (without storage)	Concentrated solar plant (central tower with 6 hrs storage)
Capital cost: engineering procurement & construction (EPC)	$/kW	2000.00	2600.00	2400.00	4700.00	4700.00	4900.00	3000.00	2750.00	6841.00	5638.00
Land cost	%	0.05	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Allowance for funds under construction (AFUC)	%	0.04	0.11	0.04	0.04	0.04	0.00	0.04	0.04	0.04	0.04
Tx/Dx intergration cost	%	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Storage (CSP)	%	-	-	-	0.08	-	-	-	-	-	-
TOTAL INVESTMENT COST	**$/kW**	**2255.00**	**3020.00**	**2631.00**	**5545.00**	**5152.00**	**5145.00**	**3289.00**	**3013.00**	**7499.00**	**6180.00**
Fixed O&M	2009$/kW/yr	24.00	39.00	116.00	66.00	66.00	16.19	54.00	170.00	64.00	66.00
Variable O&M	2009$/kWh	0.00	0.00	0.00	0.00			0.00	0.00		
Economic life	years	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Discount rate real after tax	%	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
Plant lead time	years	2.00	3.00	2.00	2.00	2.00	1.00	2.00	2.00	2.00	2.00
Fuel type		renewable	renewable	renewable	renewable	renewable	renewable	renewable	renewable	renewable	renewable
Fuel cost	$/10^6BTU	0.00		1.50	0.00			3.00			
Fuel cost	$/kWh	-	0.00	-	-	-	-	-	-	-	-
Heat rate	BTU/kWh	-	-	13500.00	-	-	-	15750.00			
Assumed load factor	%	0.27	0.50	0.80	0.40	0.25	0.16	0.80	80.00	0.20	0.40
Levelised cost of electricity	**$/kWh**	**0.12**	**0.09**	**0.09**	**0.21**	**0.31**	**0.45**	**0.12**	**0.10**	**0.55**	**0.23**
Exchange Rate R/S	ZAR/$	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
LEVELISED COST OF ELECTRICITY	**REFIT (R/kWh)**	**1.25**	**0.94**	**0.90**	**2.10**	**3.13**	**4.49**	**1.18**	**0.96**	**5.48**	**2.31**

(NERSA, 2009)

Annex 8: Currency Conversion

Exchange Rates as of 26 November 2009 (XE, 2009):

€1 = ZAR11.25