Enhancing consumers' voluntary use of small-scale wind turbines to generate own electricity in South Africa

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Abstract

This paper investigates whether South African households and small businesses can take advantage of the country's substantial wind resources to produce their own power from small-scale wind turbines in a viable way. The viability of small-scale wind turbines is assessed by means of a financial analysis based on the internal rate of return method. The recently announced wind feed-in tariff will not affect the viability of consumer-based small-scale wind turbines considered in this paper since such turbines are used to displace electricity consumption from the grid rather than supplying electricity to the grid. Thus the benefits of such wind turbines' output is valued at the grid power tariff which is saved rather than at the wind feed-in tariff rate as electricity arbitrage opportunities are non-existent because of the smallness of the turbines. The analysis found the turbines to be viable in only a few of the windiest locations in South Africa. As the competiveness of the turbines is seriously challenged by the relatively low coal-based electricity tariffs in South Africa the financial analysis also considers alternative scenarios where the turbines are supported by financial mechanisms, namely: a tariff subsidy; a capital subsidy and revenue from carbon credits. The analysis reveals that a tariff subsidy of about R1.45/kWh or capital subsidy of about R30,000/kW will be more effective in boosting the viability of consumer-based small-scale wind turbines in areas with winds of at least 5m/s. Thus, if the government's goal is renewable energy expansion in the country, there is a need for subsidizing all producers of renewable energy including those who produce it for their own consumption as they equally contribute to that goal. A tariff subsidy is however likely to be met with both political and public resistance if it means that consumers have to cross-subsidize the tariff. Also, the significant funds required for capital subsidies might not be freely available. An alternative solution would be granting soft loans to potential wind turbine buyers. Ultimately, the removal of distortionary support to coal-based electricity generation will go a long way in enhancing the viability of small-scale wind turbines.

Keywords:small-scale wind turbines; microgeneration; renewable energy; wind energy; South Africa.

1 Introduction

South Africa relies heavily on fossil fuels such as coal and petroleum products to meet its energy needs. Indeed, South Africa is the largest emitter of GHGs on the continent accounting for around 1.6% of annual global emissions and is the twelfth highest CO_2 emitter in the world (World Resource Institute, 2004). With the potential that a stricter post-Kyoto treaty calling for greater effort from

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developing countries may follow, South Africa may find itself in an expensive game of catch up if it does not start taking steps to curb GHG emissions now.

Given the costs that South Africa may incur, it is in South Africa's best interests to contribute to mitigation of climate change besides investing in adaptation to climate change. One of the ways in which this could be done is by exploiting alternative energy sources that have less adverse impacts on the environment. This is likely to be feasible since South Africa is well-endowed with renewable energy resources which remain largely untapped (DME, 2003c).

Renewable energy currently accounts for 9% of the final energy consumption of South Africans. This is derived mainly from fuel wood, a depleting resource, with modern renewable energy accounting for less than 1% of electricity consumption (DME, 2003c, Winkler, 2005). The South African government has set itself a medium term target that modern renewable energy technologies contribute 10,000GWh to final energy consumption by 2013, which is approximately 4% of the projected electricity demand (DME, 2003c).[1]

In order to quickly diversify the energy portfolio beyond the government target, South Africa should also be looking to consumer-based renewable energy technologies such as small-scale wind turbines.[2] Small scale wind turbines are advantageous given the relative abundance of wind resources in the country and the potential for their independent use by households and the private sector. In a number of countries particularly in Europe, households and businesses are taking the initiative to satisfy their own energy needs and reduce their carbon footprints through such renewable energy microgeneration.

In South Africa, microgeneration from wind turbines and other renewable energy sources has largely been overlooked on account of the country's inexpensive coal-based electricity—-the product of easy and affordable access to coal reserves and large scale government investment in the national power utility provider.[3] However, the current unstable South African energy environment might present itself as a window of opportunity for increased microgeneration from wind turbines and other renewable energy sources.[4] Accordingly, this paper evaluates the financial viability of consumer-based small-scale wind turbines in South Africa in four scenarios including those taking into consideration three financial support mechanisms that may need to be implemented to make the adoption of this technology viable in the face of cheap coal-based electricity.

On 31 March 2009, the National Energy Regulator of South Africa (NERSA) announced a series of renewable energy feed-in tariffs (REFITs) in which the feed-in tariff for wind was set at R1.25/kWh. This is only paid for supplying wind electricity to the grid. In cases where the costs of connecting to the grid are not prohibitive, which is usually the case when the wind electricity generation capacity is large, it will be rational for wind electricity generators to export their output to the grid to receive the high wind feed-in tariff and then import electricity for their own consumption back from the grid at the usual lower electricity tariff. It should however be noted from the onset that the REFITs do not affect the viability of consumer-based wind turbines considered in this paper as it is believed that the arbitrage opportunities described above are inapplicable because of the prohibitive costs of connecting to the grid emanating from the smallness of the turbines. Thus,

[1] The government's targeted renewable energy will be produced mainly from biomass, wind, solar and small-scale hydro for utilization in power generation and non-electric technologies such as solar water heating and bio-fuels.

[2] There are differing perspectives as to what range of output capacity should be categorized as small-scale. This paper follows the categorization of Ackerman et al. (2005) who regard a wind turbine with capacity under 10kW as small scale. In the analysis to follow, the viability of a 1kW and a 5kW wind turbine will be assessed. It should be noted that a 300W wind turbine would only generate enough power to electrify a sailing boat or a small cottage while a 50kW turbine would be able to provide power for the most of the energy needs on a large farm and would be a significant supplement power source for industry.

[3] It has nevertheless been applied on farms and game lodges through windmills coupled by pockets of other renewable energy technologies.

[4] The perceived risks are: 1) *risk to supply:* the national utility provider is facing serious capacity constraints which has resulted in very costly nationwide power outages and periods of load shedding; 2) *risks of tariff increases:* great uncertainty over future prices of electricity tariffs, 3) *risks of fossil fuel price hikes:* consumers are looking for greater energy security and solutions to guard themselves against rising fossil fuel prices.

the turbines under consideration are only used to displace consumption of electricity from the grid rather than supply electricity to the grid.[5]

The outline of the paper is as follows. Section 2 gives a background to wind energy use in South Africa. Section 3 presents the theoretical framework for assessing the financial viability of consumer-based small-scale wind turbines. Section 4 presents the methodology while Section 5 reports the financial analyses on the viability of small-scale wind turbines in four policy scenarios. Section 6 concludes the paper suggesting a number of mechanisms which could be employed to stimulate the small-scale wind turbine market in South Africa.

2 Background to wind use in South Africa

Modern wind power only really swung into momentum in the 1970's in the aftermath of the international oil crises (Ackerman et al., 2000). A second wind energy industry boom kicked off in Europe, particularly in Germany, Denmark, Spain, Netherlands and the United Kingdom, in the early 1990's driven in large part by incentive mechanisms. Currently Europe owns 72% of installed global capacity (White, 2005). Exponential growth in the European wind energy industry and the recent wind energy boom in the United States, China and India made wind energy the fastest growing source of new global electrical power in 2007 (Johnson, 2008). Despite this growth, Africa's contribution to the supply of wind energy production does not even constitute 1% with a paltry 234MW of installed capacity on the continent (White, 2005).

The cost of wind energy is dependent on the scale of the turbine (AWEA, 2005). The capital costs per kW of power installed for the turbine is higher for small-scale wind turbines. However the relative costs involved in the operation and maintenance (O&M) of small-scale turbines are typically lower since components are not replaced as frequently (Ackerman et al., 2005). Finally as small-scale turbines are typically erected close to the power user, transmission costs are lower relative to larger wind turbines. Despite all this, energy produced by wind power is cheaper than solar power and wave power. It is also competitive with energy generated from small-scale hydro power, large-scale hydro power, geothermal and biomass resources (See Table 1 below for international costs in US cents per kWh (UNDP, 2004)).[6]

There have been two notable endeavors to assess nationwide wind resources in South Africa: Diab (1995) and DME et al. (2006). Diab (1995) produced a *Wind Atlas of South Africa* based on data from South Africa's 170 meteorological stations and categorized wind resources according to 'geographic regions with good, moderate and low wind power potential'. The coastline and areas along the escarpment have 'good wind power potential' with mean annual speeds in excess of 4m/s at a height of 10m. DME et al. (2006) created the *South African Renewable Energy Resource Database (SARERD)* wind resource model with a more detailed range of mean annual wind speeds at a spatial scale of one square kilometer (see figure 1 below). The wind resource model also shows that South Africa has substantial wind resources along the coastline and the escarpment. In fact, in a number of promontories along the coast and along certain stretches of the Dranskenberg escarpment in the Eastern Cape and Kwazulu-Natal wind speeds average in excess of 5m/s or 6m/s.[7]

Van de Linde and Sayjah (1999) forecast that South Africa could meet 5% to 6% of its energy demands with wind power. However, DME (2004) calculates the economically feasible annual production to be 0.23PJ, the equivalent to 1% of the country's electricity consumption while Banks and Schaffler (2005) estimate the economically feasible output to be 0.38PJ. The bottom line is that wind is a candidate renewable energy source in South Africa and the spatial distribution of the wind

[5] Thus, the benefits of wind turbines output is valued at the grid power tariff which is saved rather than at the wind feed-in tariff rate.

[6] Wind energy has the potential to be as economical as coal-generated power when performing optimally.

[7] However, one cannot make micro-level performance calculations with this data and project developers would have to conduct their own micro-siting wind resource studies accounting for various specific topography attributes such as terrain roughness and shadow effects (Schaffler, 2001, White, 2005).

resource will most likely be conducive to small-scale harvesting technologies. This is corroborated by actual statistics of current wind exploitation. Wind turbines have four general types of applications, namely grid-connected rural mini-grid off-grid and hybrid.[8] Table 2 below illustrates the total capacity and estimated annual production for each of these different types of applications in South Africa (DME, 2003a).[9]

Despite South Africa's electrification promotion programme, roughly a third of the population, the majority of who reside in rural areas, is still isolated from the national-grid (Winkler, 2005). Total electrification of the nation by 2010 has been one of the primary goals of government. To help achieve this, the government has subsidized pilot projects, predominantly solar systems, in a number of rural areas which have had little success (DME, 2003a). Small-scale wind turbines may be more suitable in the rural-grid context as they offer several advantages over other renewable energy technologies: i) relatively low capital investment costs in comparison to other renewable energy technologies; ii) low operation and maintenance (O&M); iii) many of those areas which do not have access to electricity are situated along South Africa's windswept coastline and iv) significant storage potential (DME, 2003a).

The South African small-scale wind turbine industry is in its infancy. Currently, there are about six small-scale turbine manufacturers including Kestrel Wind Turbines, Winglette Wind Machines, African Windpower, but also a number of local distributors who import small-scale wind turbines predominantly from the United States and Europe. Kestrel Wind Turbines, a well established manufacturer, is reported to have sold 200 turbines by 2003, since establishment in 1999 (DME 2003a). Low electricity tariffs, lack of product awareness by South African consumers, large initial capital investments required by the consumer, an inadequate policy support framework for wind energy and difficulties in securing financing for a technology that may be perceived as unproven in the South African context are the greatest obstacles (DME, 2003a).

3 The theoretical framework for assessing the viability of small-scale wind turbines

This paper considers the financial viability of consumer-based small-scale wind turbines with a view to determine the conditions under which households and enterprises will voluntarily adopt this technology. There is a range of methods used to establish financial viability of small-scale wind turbines and other renewable energy technologies. The most prominent ones are Supply Curve Analysis, the Payback Period, the Net Present Value (NPV), the Internal Rate of Return (IRR) and Cost-benefit Analysis (CBA).

Supply Curve Analysis is a modeling technique which simulates the amount of a product a producer would be able to profitably supply at various price levels over time. In 2004 the DME coordinated a study entitled *The Economic and Financial Calculations and Modeling for the Renewable Energy Strategy Formulation* with the objective of identifying the renewable energy technologies which would be most appropriate for the South African context (DME, 2004). The study generated models of financial, economic and socio-economic supply curves for static and dynamic[10] scenarios for the various renewable energy technologies using wind, solar, hydro, biomass, etc. Assuming a 20% cost reduction over the long-run period of ten years, the study concluded that the Long Run Supply Curves for wind energy for all wind speeds were above the Long Run Marginal Cost[11] curve

[8] Small-scale wind turbines providing power to consumers connected to the grid offer further benefits: (i) as they are located in close proximity to the consumer they will reduce transmission and distribution losses; (ii) potentially ease the capacity constraints on Eskom; (iii) improve the quality of the electricity supply (Schaffler, 2001).

[9] Regrettably these statistics do not account for wind turbines installed within the last five years, such as those at the Darling Wind Farm.

[10] The static scenario is based on current market prices while the dynamic one is based on forecasted future prices which account for economies of scale and technological improvements in the renewable energy technology industry.

[11] The average cost of coal fired power is 0.2526c/kWh.

for coal-fired power and thus wind energy would remain commercially unviable in the medium term. If it was really necessary for wind energy to be enhanced then it would require subsidization in order for it to be competitive with coal-based power.

The Payback Period method determines the period of time that the cumulative net revenue from an investment project takes to equal the original investment (Bannock et al., 2003). It is a commonly used but crude method as it does not account for profits over the whole lifetime of the investment or the time-profile of cash flow (Bannock et al., 2003). It is a popular approach among manufacturers of small-scale wind turbines and other renewable energy technologies to validate the viability of their product. However, the payback period approach does not properly account for the time value of money, risk, financing or other important considerations such as the opportunity cost. Bahaj et al. (2007) performed a study on the viability of small-scale wind turbines for domestic dwellings in the urban environments in the United Kingdom using the Payback approach. The study found that payback periods for United Kingdom urban environments were not favourable, but at the windiest sites in the United Kingdom in coastal and elevated inland regions the payback periods were more promising (Bahaj et al., 2007).

The NPV method determines the viability of an investment project by calculating the difference between the discounted profit flows over the expected lifetime of the project and the initial capital investment (Bannock et al., 2003). A project will be profitable if the NPV is greater than zero i.e. the discounted profit flows exceed the capital costs of the investment. In a feasibility study of a 30MW wind farm in the Philippines the NPV method was applied to assess the viability of the farm in a variety of different scenarios (Painuly, 2004). These scenarios considered a number of variations in the base parameters such as adjustments in the electricity sales price, total generation and the operation and maintenance costs (O&M) as well as assess several financial scenarios. In several of these scenarios the NPV yielded a positive value indicating the wind farm might be viable.

The IRR method is a widely used method for assessing the viability of an investment. The IRR is the discount rate which delivers a net present value of zero on future cash flows (Spalding-Fecher, 2000). It can also be expressed as the rate at which returns on an investment outweigh the opportunity cost. The opportunity cost is the returns that would have been earned on an alternative investment. The IRR for an investment therefore has to be superior to the opportunity cost for the investment to be viable (White, 2005). This minimum expected rate of return is known as the hurdle rate or weighted average cost of capital (WACC). All other things equal, the investment with the highest IRR is the most attractive investment. IRR should not be used to compare investments of different scale and criteria and the IRR value is not an indicator of the volume of profits.

A CBA is an evaluation of an investment project based on the consideration of all the social and financial costs and benefits pertaining to that project (Bannock et al., 2003). A project should go ahead if the aggregate of the benefits outweighs the costs. Monetizing the value of certain costs and benefits often presents difficulties during a CBA (Bannock et al., 2003). Kaldellis and Kavadias (2007) carry out a CBA to investigate the viability of remote hybrid wind–diesel stand-alone systems on a number of the Aegean Sea islands in Greece. They found that for some of the islands these small-scale hybrid wind-diesel systems were cost-effective.

Of all these methods, the IRR is preferred in this paper because of its relative suitability to the decision-making process surrounding the acquisition of assets such as small-scale wind turbines by households and small enterprises. Some studies have used the payback method when dealing with households while others use the modified IRR when dealing with firms. In contrast, this paper deals with both households and small enterprises as the primary decision makers. It is therefore this paper's view that the IRR would be an appropriate compromise for the decision making processes by both households and small enterprises.[12]

[12] It should be noted that had we been dealing with only small enterprises as the decision makers then the modified IRR would have been more suitable as it takes into account the fact that firms reinvest the returns earned during the lifetime of the investment at possibly variable rates.

4 Methodology

CSIR et al. (1998) investigated renewable energy sources for rural electrification in South Africa. The project also collected wind speed data for 98 sites in South Africa, 15 of which had a mean annual wind speed in excess of 5m/s. This paper investigates the financial viability of consumer-based small scale-scale wind turbines in the top ten windiest sites in South Africa as listed in CSIR et al. (1998). In descending order, from windiest to least windy, these sites are Gains Castle, KwaZulu Natal; Springbok, Northern Cape; De Aar, Northern Cape; Langebaan, Western Cape; Simonstown, Western Cape; Cape Town, Western Cape; Koningnaas, Northern Cape; Ixopo, KwaZulu Natal; Geelbek, Western Cape; Noupoort, Northern Cape. The financial viability analysis involved calculations of the IRR for each site for a 1kW and a 5kW wind turbine in four scenarios including those taking into consideration three financial support mechanisms that may need to be implemented to make the adoption of this technology viable in the face of cheap coal-based electricity. The three financial support mechanisms considered are a tariff subsidy, a capital subsidy and carbon credit financing. The four policy scenarios under which the IRR is computed can therefore be listed as follows:

1. The viability of small scale wind turbines in a market with standard electricity tariff rates, no capital subsidies and no financing from the sale of carbon credits (i.e. the status quo);
2. The viability of small scale wind turbines in a market with *a tariff subsidy* on top of standard tariff rates, no capital subsidies and no financing from the sale of carbon credits;
3. The viability of small scale wind turbines in a market with standard tariff rates, *a capital subsidy* and no financing from the sale of carbon credits;
4. The viability of small scale wind turbines in a market with standard tariff rates, no capital subsidies and *revenues from the sale of carbon credits*.

The IRR of a small-scale wind turbine is a function of the initial capital investment and the net benefit flows over the lifetime of the wind turbine.[13] The net benefit flows in each period comprise the costs and benefits associated with the wind turbine for that period. It is assumed the full value of the initial capital investment is incurred in the initial period and the costs incurred in the remaining periods are equal to the annual O&M costs. It is assumed that the annual O&M cost component covers all monitoring, metering, repair, replacement, insurance, administration and any other fixed or variable costs incurred during the lifetime of the small-scale wind turbine (EWEA, 2005). For the purposes of this study these are assumed to be the only costs associated with a small-scale wind turbine.[14] Based on the average estimates for the South African small-scale wind turbine market, the value for initial capital investment are set at R45,000 for the 1kW turbine and R200,000 for the 5kW turbine.[15] In reality a level of economies of scale might be achieved in the manufacture of a 5kW turbine with the result that the mean cost per kW installed for the 5kW turbine would be lower than that for a 1kW. However, the economies of scale will also be militated against by the fact that larger high voltage turbines need to be located a little further away from the point of use of electrical power due to noise, etc. The value of the annual O&M cost is fixed at 1% of the initial capital cost investment for every year throughout the turbine's lifetime (Sagrillo, 2004). This is the estimated annual average cost of O&M for small-scale wind turbines in the United States as determined by the AWEA (2007).

[13] Kestrel Wind turbines indicates that small scale wind turbines have a design life of 20-40 years (http://www.kestrelwind.co.za/faq.asp). This paper takes the lower bound as the lifetime of the wind turbine.

[14] In a general model of this nature, we do not make any provision for depreciation. The effect of such omission, if significant, is to overstate the IRR.

[15] The figures include the cost of the wind turbine, tower, battery bank, inverter, standard accessories and installation. Note that the CaBEERE baseline study on wind energy used an estimate of R15,000 per kW capacity installed for local manufacturers and R20,000-R30,000 per kW installed for imported turbines (DME, 2003a).

Since it is far more complex to measure the benefits and thus the viability of small-scale wind turbines for consumers who are not connected to the national grid, this paper will focus on the viability of small-scale wind turbines for consumers who are grid-connected. The yearly benefit derived from a small-scale wind turbine is therefore potentially equal to three components namely (i) the amount the consumer saves by generating their own electricity instead of purchasing it from the grid, (ii) the annual revenue from a tariff subsidy if applicable and (iii) the revenue generated from the sale of carbon credits if the small-scale turbine owner is engaged in the carbon market. The yearly savings made by replacing an amount of electricity normally purchased from the grid is determined by multiplying the annual turbine harvest by the tariff rate charged by the power utility.[16]

The annual harvest is calculated with the use of a widely used power performance curve formula which determines the quantity of power a wind turbine can extract from the wind in an hour. See for example Somerville (2006). It is represented by the following formula:

$$P = \frac{1}{2}\rho A V^3 C_p \tag{1}$$

where P is the power output of the small-scale wind turbine, ρ is the air density, A is the area swept by the turbine's rotor blades, V^3 is the cube of the mean hourly wind speed and C_p is the efficiency of the turbine in capturing wind power. The output is then multiplied by the number of hours in a year to calculate the annual harvest. As South Africa's most abundant wind resources are generally located along the country's coastline, the air density factor of $1.225kg/m^3$, which is the air density at sea level, is used (Somerville, 2006). The area swept by the turbine's rotor blades is a function of the diameter of rotor blades. The observed rotor diameter tends to range from 2.5-3.0m for a 1kW turbine and 5.0-6.5m for a 5kW turbine. The financial analysis for the two turbines therefore assumes a 3.0m diameter for a 1kW turbine and a 6.0m diameter for a 5kW turbine.[17] The annualized mean hourly wind speed data for the top ten windiest locations in South Africa is used in the performance curve calculations. Since small-scale wind turbines are able to achieve high rotor speeds a C_p mean value of 0.45 is assumed.[18]

On 31 March 2009, the National Energy Regulator of South Africa (NERSA) announced a series of REFITs in which the feed-in tariff for wind was set at R1.25/kWh. Such feed-in tariffs do not directly benefit those wind turbines which are used to displace consumption of electricity from the grid. Such tariffs are meant for those wind turbines that supply electricity to the grid. This paper focuses only on those small-scale wind turbines which are used to displace grid electricity consumption. The tariff rates used in the analysis are represented by the Business rate of 38.34c/kWh and the Homepower rate of 45.05c/kWh as charged by Eskom to non-municipal customers (e.g. small businesses and government institutions) and medium to high usage residential users respectively as of 1 July 2008 (Eskom, 2008).[19] In order to fund the capacity expansion and demand side management to ensure stability in electricity supply Eskom would need to increase tariffs over time. Although there is a plethora of factors[20] which may influence the level of tariff adjustment in South Africa in the future, for the purposes of this financial model it is assumed that electricity tariffs will increase on average 10% per annum over the lifespan of the wind turbine.

The prices of carbon credit are dependent on the risk involved in the project and as risks can vary greatly credits are traded at a broad range of prices (Genesis, 2008). For the purposes of the

[16] The financial analysis assumes that transmission, voltage, network, service and other surcharges are fully reflected in the tariff.

[17] The rotor area is πr^2.

[18] The maximum value of this variable is 0.59, known as the Betz limit.

[19] Eskom also has lower tariffs namely the Homelight and Ruralflex which are tailored for low income consumers and rural users respectively. The Businessrate 4 and Landrate 4 tariff categories are higher and are designed for high usage customers. Using any of these lower rates would act to reduce the IRR while using the higher rates has the opposite effect.

[20] It should be noted that electricity prices in South Africa are closely tied to the coal and diesel price, which in recent times have been on the rise (Eskom, 2008b)

financial analysis the range of R50-R400 per ton of CO_2 will be investigated. This range is consistent with the ranges of prices that carbon credits can fetch in markets (Genesis, 2008). It is assumed that the small-scale turbine owner has secured a contract with a willing buyer and that the carbon credit price is a forward price fixed over the lifetime of the turbine. The baseline emissions level, which is the mean level of carbon dioxide emissions in tons of CO_2per kWh for the area where the renewable energy project is installed, in this analysis will be assumed to equal to 0.000963 tons of CO_2/kWh. This is the validated baseline level for the national grid as recently calculated by Eskom (Eskom, 2007). The emissions level for both the 1kW and 5kW turbines is zero. Given a baseline level of emissions, total carbon savings in tons (ΔCO2) from an emissions reduction project can be calculated as follows:

$$\Delta CO2 = (BE - AE)Hn \tag{2}$$

where BE=baseline emissions in tons per kWh, AE=actual emissions in tons per kWh, H= the amount of electricity generated annually and n=the lifetime of the project. The carbon revenue (CR) generated from the project is the product of the total carbon savings (ΔCO2) and the negotiated price of the carbon credit (P_c) i.e.

$$CR = P_c \Delta CO2 \tag{3}$$

As indicated earlier, one of the South African manufacturers indicates that small scale wind turbines have a design life of 20-40 years. This paper takes the lower bound as the lifetime of the wind turbine. This is also consistent with other studies such as Dayan (2006) that estimate the average lifetime of a small-scale wind turbine to be 20 years.

4.1 Discussion of results

In each of the four scenarios the viability of both the 1kW and 5kW small-scale wind turbines will be determined by calculating and interpreting the IRRs for the 10 windiest sites in South Africa. As discussed in the theoretical framework above the IRR for an investment needs to exceed the hurdle rate or WACC to be viable. The WACC can also be defined as the sum of the risk-free rate plus a risk premium (Kantor & Marchetti, 2005). The R157 bond is used as a proxy for the tax adjusted risk-free rate in South Africa, the current return on this bond is 9.325% (Cape Times, 2008). The equity market risk premium in South Africa is estimated at 5 to 5.5% (Kantor & Marchetti, 2005). Therefore the WACC of the equity market in South Africa is just under 15%. Considering the uncertainty regarding future technologies and the general energy environment in South Africa, for the purposes of this paper a WACC, similar to that in the equity market, of 15% is assumed.

4.2 Results discussion for Scenario 1:

The first scenario that is considered in the financial analysis is the case where there is no support from any financial mechanisms. This implies that either the Business rate or Homepower rate tariff is applied, no tariff subsidy or capital subsidy system is in place and no revenue is generated from carbon credits. As pointed out earlier, the WACC of 15% will be used. The IRRs for the selected sites are given in table 3 below.

The IRR for a 1kW turbine located at eight of the ten of the locations, barring Gains Castle and Springbok, will not exceed the hurdle rate and hence will not be viable at both the Business rate and Homepower rate tariffs. A 1kW turbine will yield exceptionally high returns (IRR of at least 52%) at Gains Castle on account of the extremely high wind speeds at this location. In the calculations for a 5kW turbine, Gains Castle and Springbok were the only locations where investment would be viable particularly in the presence of the Homepower rate with the IRR's for the other eight locations being inferior to the WACC. The 5kW turbine situated at Gains Castle will once again produce an IRR well in excess of the hurdle rate.

Based on the assumptions made in this financial model a mean annual wind speed of just over 8m/s is the minimum wind speed required for a 1kW turbine to be viable at any location. Although investments in small-scale wind turbines according to the specifics of this financial model are not considered to be viable at most locations, some investors, for instance an investor with a greater risk appetite or a reduced hurdle rate as a result of a lower cost of finance or a reduced hurdle rate owing to the need for a reliable and dependable service may be able to justify an investment at these locations. Households and small businesses which may be paying a higher tariff rate may be able to invest viably in a 1kW turbine at some of these locations.

4.2.1 Results discussion for scenario 2:

In this scenario, the case where there is a tariff subsidy granted to the small-scale turbine owner is considered. The tariff subsidy would take the form of a 20 year long Power Purchase Agreement (PPA) which will pay the small-scale wind turbine owner a certain amount per kWh of electricity generated for own consumption. The annual revenue earned by a turbine owner from a tariff subsidy will therefore be a product of the output of a turbine over a year and the rate of the tariff subsidy. The benefits for the turbine owner are therefore the savings based on the usual (either Businessrate or Homepower rate) tariff from substituting electricity from the grid with the wind generated electricity and the revenue secured from the tariff subsidy. In this scenario the turbine owner does not receive any capital subsidy nor carbon credit revenue.

This scenario analyzes what level of tariff subsidy would be required by a wind turbine owner in order to achieve the WACC of 15% at any location given a specific wind resource. For this scenario an annual mean wind speed of 5m/s, a wind resource satisfied by the 10 locations considered in this study and which would generally be considered to be above average, will be used as a benchmark. While a tariff subsidy can take a number of forms, for the purposes of this analysis, the nature of the tariff subsidy is of less interest than the magnitude of the subsidy necessary to realize a viable small-scale wind turbine project.

The following results can be deduced from these sensitivity analyses ascertaining the extent of the tariff subsidy required to obtain an IRR of 15% at any location with a mean annual wind speed of 5m/s. The relationship between the IRRs of the 1kW and 5kW turbines and the tariff subsidies approximate linear relationships as is evident from Graph 1 below. For the 1kW turbine, a tariff subsidy of at least R1.30 would be needed to make the turbine viable in the presence of the Homepower rate while R1.40 would be needed in the presence of the Business rate. For the 5kW turbine, tariff subsidies of R1.40/kWh above the Homepower rate and R1.60 above the Business rate are required to overcome the WACC. The tariff subsidy might not need to be this high for investors with a greater risk appetite or a reduced hurdle rate as a result of a lower cost of finance or a reduced hurdle rate owing to the need for a reliable and dependable service. However, some level of tariff subsidy seems indispensible.

The need for such huge subsidies to enhance the viability of small-scale wind turbines should not necessarily be a cause for budgetary concerns. The message coming through from the results is that the viability of wind turbines can only be enhanced if they are competing with sources of electricity which are more expensive than the current cheap coal-based electricity. In other words, the results merely confirm that coal-based electricity in South Africa is rather too cheap for renewable energy sources such as wind to be competitive. The major reason why coal-based electricity is cheap is the excessive support which the power utility company has been given by government. Removal of such distortionary support would effectively provide the required incentives for the wind turbines use. Thus, the withdrawal of distortionary support acts in the same manner as tariff subsidies for renewable energy generation.

4.2.2 Results discussion for scenario 3:

This scenario assesses the case where owners of small-scale wind turbines who are located at a site with a mean annual wind speed of 5m/s will receive a capital subsidy grant. It is assumed standard Business rate tariff charges apply and that there are zero revenues from carbon credits.

The largest expense to potential investors in small-scale wind turbine systems is the high initial capital investment. This initial capital investment makes up the dominant share of the total costs of a small-scale wind turbine and thus if this high capital cost could be reduced by a capital subsidy it would be expected that the viability of the turbines would be greatly enhanced. Therefore in scenario 3 the impact of a capital subsidy on the viability of a 1kW and 5kW small-scale wind turbines is analyzed. This capital subsidy might be a once-off grant or may be divided up and paid out at various intervals over the lifetime of the turbine. In this scenario it has been assumed the full capital subsidy grant is handed out to the consumer at the time of initial investment (i.e. in year 0).

A sensitivity analysis was performed in order to gauge the impact of changes in the proportion of the total initial capital investment subsidized on the IRR of the turbines. The results of this analysis are depicted in the sensitivity plot below (see Graph 2) which shows that for an increase in level of subsidization on the initial capital investment there is an exponential growth in the IRR for both turbines. A capital subsidy grant of at least R33,000 is required by the owner of a 1kW turbine at a location where the mean annual wind speed is 5m/s in order for the investment to be viable. The 5kW turbine will require a capital subsidy grant of R30,500 per kW installed capacity in order to generate a rate of return greater than WACC.[21] Capital subsidy grants thus theoretically have the potential to enhance the viability of small-scale turbines on a national scale. The efficacy of capital subsidies as instruments of enhancing the use of wind turbines signals the need to assist potential users with initial installation costs. An alternative solution which is likely to give the same result would be granting soft loans to potential wind turbine buyers. Resources for use in this way of promotion of renewable energy generation could be pulled out of the distortionary support to the power utility alluded to above.

Source: Own computations

4.3 Results discussion for scenario 4:

This final scenario investigates the case where a small-scale turbine owner with a turbine located at a site with a mean annual wind speed of 5m/s has secured a twenty year contract of sale for forward priced carbon credits from a willing buyer in the carbon market. It is assumed that either of the standard tariff rates applies and the turbine owner is not receiving any form of capital subsidy or tariff subsidy. The assumptions are also made that there are no transaction costs[22] incurred by the small-scale turbine owner and the small-scale turbine projects meets additionality or any other requirements for a carbon credit trading project. A sensitivity analysis was undertaken to assess the impact of carbon credit revenue on the viability of the two types of small-scale wind turbines (see Graph 3).

Whilst the viability of small-scale wind turbines in South Africa can be potentially enhanced through the sale of carbon credits to willing buyers, the revenues generated from carbon credit sales, even a carbon credit price of R400/tCO_2, a price at the very top end of the carbon credit market, will be insufficient to boost the IRR's for both a 1kW and 5kW turbine beyond the hurdle rate. Some forecast that the prices of carbon credits will climb way above current levels in the near future as concerns over climate change continue to mount. However prices of at least R2,700 per tCO_2 saved by owners of 1kW turbines and exorbitant prices of around R3,150 per tCO_2 saved by owners of 5kW turbines will be required in order for investments in these respective turbines to be viable.[23] The reason such high carbon credit price hikes would be required is because the annual

[21] The capital subsidy might not need to be this high for investors with a greater risk appetite or a reduced hurdle rate as a result of a lower cost of finance or a reduced hurdle rate owing to the need for a reliable and dependable service. However, as said earlier, some level of subsidy seems indispensible.

[22] There can be a wide range of transaction costs involved in carbon credit trading such as monitoring, verification, registration, legal and administration costs.

[23] The carbon credit prices might not need to be this high for investors with a greater risk appetite or a reduced hurdle rate as a result of a lower cost of finance or a reduced hurdle rate owing to the need for a reliable and dependable

avoided emissions of CO_2 for the turbines are low and thus the revenues from sales of carbon credit are outweighed by the large initial capital investment. Thus the cash flows of small-scale turbines are not highly elastic to changes in carbon credit prices. If the transaction and other costs were factored in this analysis it would prove to be even more unviable for a small-scale turbine project to participate in the carbon market.

4.4 Mechanisms for growth and development of the SA small-scale wind turbine market

Wind conditions are critical to the performance of the small-scale wind turbines and this technology is likely to be a viable investment for voluntary adoption in select locations in South Africa where mean annual wind speeds are high. For many other locations, despite abundant wind resources, sufficient savings on avoided coal-based electricity will not be made for investment in these turbines to be considered economical. The financial analysis carried out in this paper demonstrated that the viability of small-scale wind turbines can be enhanced notably if the investment is supported by financial mechanisms such as a tariff subsidy or capital subsidy or a carbon market system. Therefore if this technology is going to be employed on a significant scale it is likely that it will need to be backed by a financial mechanism of some form.

There are a number of policy options that government can pursue to facilitate the viability of consumer-based microgeneration renewable energy technologies like small-scale wind turbine systems in South Africa; these include investment incentives in the form of low interest loans, capital subsidy grants or tariff subsidies (Kamins, 2007).[24]

The REFITs announced by NERSA will not be of any advantage to consumer-based small-scale wind turbine owners as the function of their turbines is predominantly to provide energy for their own consumption and not for export back into the grid. If the government's goal is renewable energy expansion in the country, there is a need for NERSA to also adopt some form of tariff subsidy, which pays the independent power provider based on the sum of electricity that is generated from renewable energy regardless of whether this electricity is consumed by the producer or distributed back to the grid. Indeed, the major emphasis of the feed-in tariff should be to increase the share of renewable energy such as wind in the national energy portfolio. This form of tariff subsidy is instituted in the UK under the Renewables Obligation Certificate programme (Bahaj et al., 2007). This form of tariff subsidy will be more advantageous to small-scale wind turbine owners. The financial analysis for the scenario of a tariff subsidy indicates that a subsidy of about R1.45/kWh will be required for consumer-based turbines to be viable in areas with winds of at least 5m/s.

The single most significant financial barrier for investors in small-scale wind turbines is the high initial capital investment required to install the turbine. The income per capita level in South Africa being considerably lower than in developed countries means the majority of South Africans do not have access to the equity to afford this large initial investment. Capital subsidy grants can reduce this capital cost and by doing so significantly enhance the viability of the turbines. The financial analysis performed in this paper indicated that capital subsidies for both 1kW and 5kW turbines would need to be substantial in order for investment to be viable. The likes of REFSO or the Energy Development Corporation (EDC)[25] could potentially provide such subsidies but this would require

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service. However, as said earlier, an additional price incentive seems indispensible.

[24] At present the South African renewable energy policy framework offers no known appropriate facility which directly supports investment in consumer-based microgeneration renewable energy technologies. Some capital subsidy grants are available from the Renewable Energy Finance and Subsidy Office (REFSO), a subsidiary of the DME. However, these subsidies are only available to developers of renewable energy projects that have a capacity of at least 1MW and thus would not be accessible to owners of small-scale wind turbines (DME, 2008b). Subsidies can be also secured through the Department of Trade and Industry (DTI) but these too are directed at larger scale projects.

[25] The EDC, an organ of the Central Energy Fund, is a commercial enterprise whose primary objective is to assist the government in achieving the 10,000GWh target for renewable energy by 2013 through facilitating and mobilizing the implementation of renewable energy projects. The EDC aims to achieve this by amongst other things providing

a significant commitment of funds on their behalf to grant such subsidies. The likelihood that such funds would be freely available is minimal especially considering REFSO have only handed out R4 million in grants to date (DME, 2008a). Further low-cost financing in the form of low-interest loans or equity can be sought from a host of local and international development banks and organizations. For individual small-scale wind turbine owners such finance options may not be accessible but if some nature of partnership could be formed that united owners of small-scale wind turbines in South Africa perhaps access to finances is likely to become easier.

The global carbon market is growing rigorously doubling in size in 2007 as climate change moves increasingly into the foreground of government and corporate agendas (Genesis, 2008). The European Union (EU) Emissions Trading Scheme, which is a cap and trade system implemented within the EU, constitutes 78% of this market (Genesis, 2008). Although developing countries cannot benefit from this scheme, the trade of carbon credits in other carbon markets has supported the development of many renewable energy projects in the developing world in the last several years. Renewable energy project developers in non-industrialized can access carbon credits through the CDM market or voluntary markets.

The financial analysis of the scenario where small-scale wind turbine owners are active in the carbon market shows that revenues generated through the sale of carbon credits can to a limited extent enhance the viability of turbines, assuming that transaction and other costs are zero. It is important to note that carbon credit prices would need to be significantly higher than any carbon credit is valued at in a current market in order for a 1kW and 5kW turbine to be viable at a location with mean annual wind speed of 5m/s. As small-scale wind turbine owners are unlikely to be able to secure such a price over the lifetime of the turbine, especially given the uncertainty in the carbon credit market post-2012 when Kyoto expires, suggests that a capital or tariff subsidy would be a more effective support mechanism. Transaction costs will need to be kept to minimum in order for small-scale wind turbine owners to benefit at all from being part of a carbon market.

While low existing tariffs and high initial capital investments are probably the biggest barriers in the small-scale wind turbine market in South Africa, there are also barriers such as lack of public awareness of the benefits of small-scale wind turbines in South Africa. The South African government can play a significant role in removing these barriers in order to create an environment in which small-scale wind turbines can compete on a level playing field with fossil-fuel based and other sources of power. Government could achieve this through creating appropriate economic incentives and through programmes which disseminate information and market small-scale wind turbines in order to overcome a lack of public awareness.

5 Conclusion

At the current rate of development in the renewable energy sector it seems unlikely that the South African government will reach the medium-term of 10,000GWh of additional renewable energy power by 2013. While the government has devoted minimal resources into pushing microgeneration technologies, the wide-scale application of small-scale wind turbines can potentially make a significant contribution in assisting government meet this target. Small-scale wind turbines offer an opportunity to South African consumers to protect themselves against the impacts of power-outages and load-shedding and rising fossil fuel and tariff prices; to reduce their personal carbon footprint and assist South Africa in curbing its high level of emissions; and to improve the quality of their own power supply. This paper looked at the financial viability of those consumer-based wind turbines for which electricity arbitrage opportunities to take advantage of the recently announced REFITs are non-existent because of the smallness of the turbines. The financial analysis suggested that under certain conditions the benefits from the turbines would outweigh the costs to consumers and if they were to be supported by financial mechanisms they would be even more viable. A tariff subsidy of

equity, loans and expertise to viable renewable energy projects.

about R1.45/kWh (i.e. based on the total amount of electricity generated) or an upfront capital subsidy grant of about R30,000/kW would appear to be the most effective form of financial support and will offer the greatest assistance in overcoming the obstacles presented by the low tariff rates in South and the high initial capital costs of the turbines, particularly for areas with winds of at least 5m/s. The subsidies might not need to be this high for investors with a greater risk appetite or a reduced hurdle rate as a result of a lower cost of finance or a reduced hurdle rate owing to the need for a reliable and dependable service. However, some level of subsidy seems indispensible. Thus, if the government's goal is renewable energy expansion in the country, then in addition to its recent announcement of REFITs, there is a need for NERSA to also adopt some form of tariff subsidy, which pays the independent power provider based on the sum of electricity that is generated from renewable energy without a requirement to export it to the grid. Furthermore, capital subsidy grants can reduce the capital cost and by doing so significantly enhance the viability of the turbines. The financing of these support schemes will however present a number of challenges considering the financial constraints of government and the utility provider and a population that is not likely to be willing to cross-subsidize such schemes. Low-cost financing in the form of low-interest loans might need to be sought from a host of local and international development banks and organizations. Ultimately, besides the foregoing, the removal of distortionary support to coal-based electricity generation will go a long way in enhancing the viability of small-scale wind turbines.

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Table 1: World Energy Assessment Report's international cost comparison of renewable energy alternatives

Renewable Energy Alternative	2001 energy costs	Potential future energy cost
Wind	4-8 ¢/kWh	3-10 ¢/kWh
Solar photovoltaic	25-160 ¢/kWh	5-25 ¢/kWh
Solar thermal	12-34 ¢/kWh	4-20 ¢/kWh
Large hydropower	2-10 ¢/kWh	2-10 ¢/kWh
Small hydropower	2-12 ¢/kWh	2-10 ¢/kWh
Geothermal	2-10 ¢/kWh	1-8 ¢/kWh
Biomass	3-12 ¢/kWh	4-10 ¢/kWh
Coal (comparison)	4¢/kWh	

Source: UNDP (2004)

Table 2: Capacity and annual wind power production for different wind turbine applications in South Africa

Type	Capacity (kW)	Estimated Annual Production (MWh)
National grid	3,160	5,000
Rural grid	45	111
Off grid	510	1,117
Borehole windmill	12,000	26,000
Exploited wind energy in South Africa	**15,715**	**32,228**

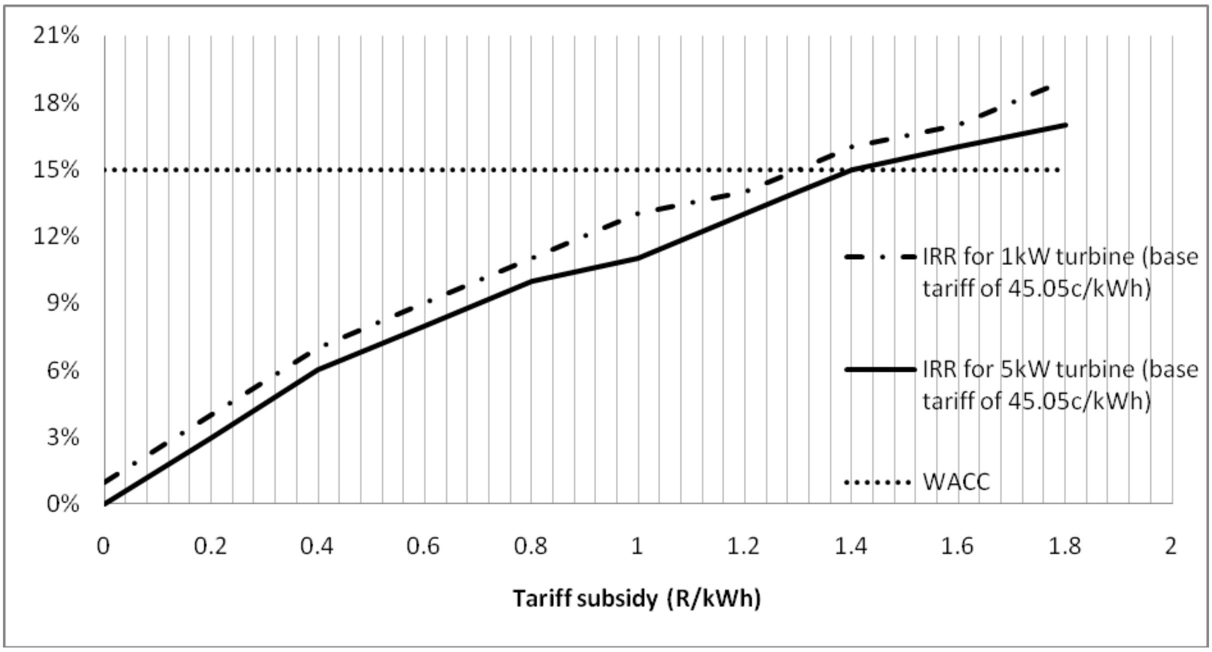
Source: DME (2003a)

Table 3: IRR's for the 1kW and 5kW turbines at various locations

Site	Annual mean wind speeds	IRR for 1kW turbine (38.34c/kWh)	IRR for 1kW turbine (45.05c/kWh)	IRR for 5kW turbine (38.34c/kWh)	IRR for 5kW turbine (45.05c/kWh)
Gains Castle	13.94	52%	60%	48%	55%
Springbok	8.27	15%	17%	14%	16%
De Aar	6.88	9%	10%	7%	9%
Langebaan	6.88	9%	10%	7%	9%
Simonstown	6.65	7%	9%	6%	8%
Cape Town	6.63	7%	9%	6%	8%
Koningnaas	6.2	5%	7%	4%	6%
Ixopo	5.82	4%	5%	3%	4%
Geelbek	5.62	3%	4%	2%	3%
Noupoort	5.6	3%	4%	2%	3%

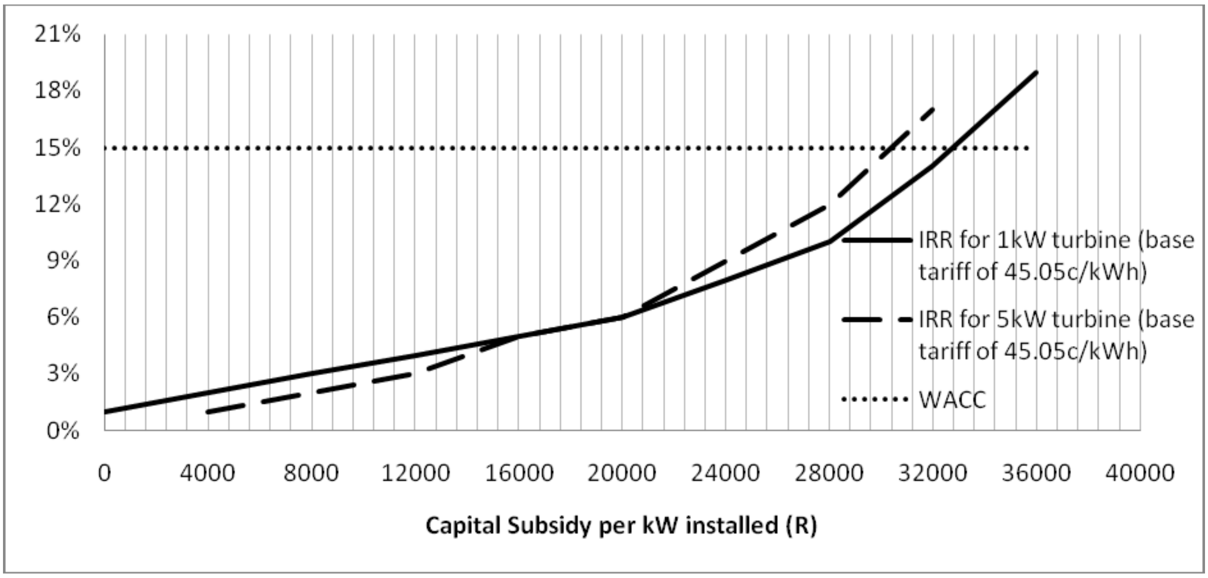
Source: Own computations

Graph 1: The impact of tariff subsidies on IRR values of the 1kW and 5kW turbines



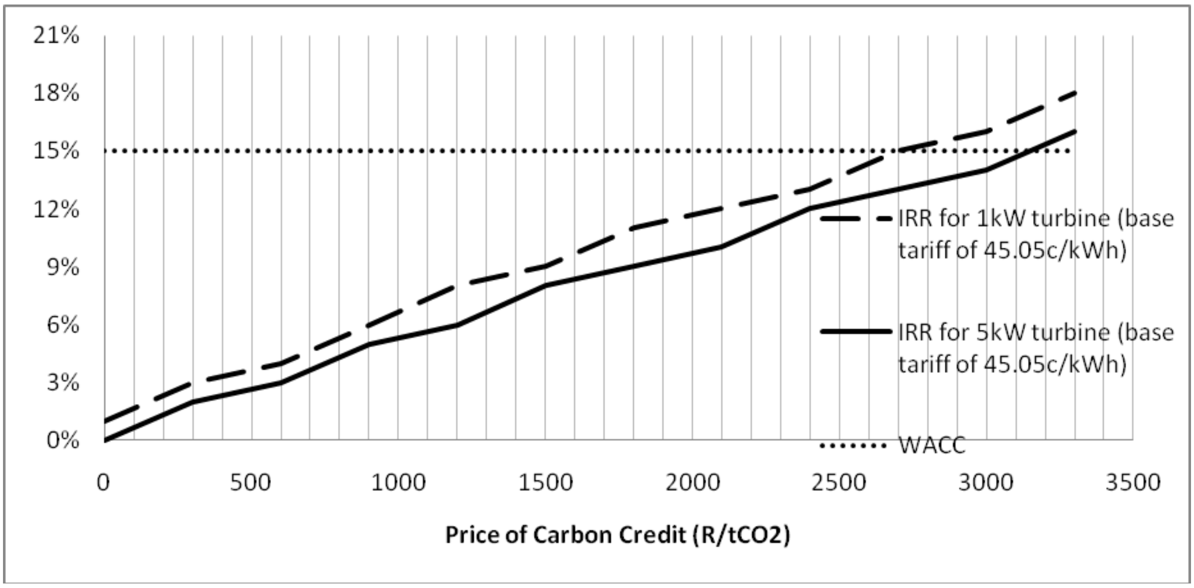
Source: Own computations

Graph 2: The impact of a capital subsidy on the IRR values of the 1kW and 5kW turbines



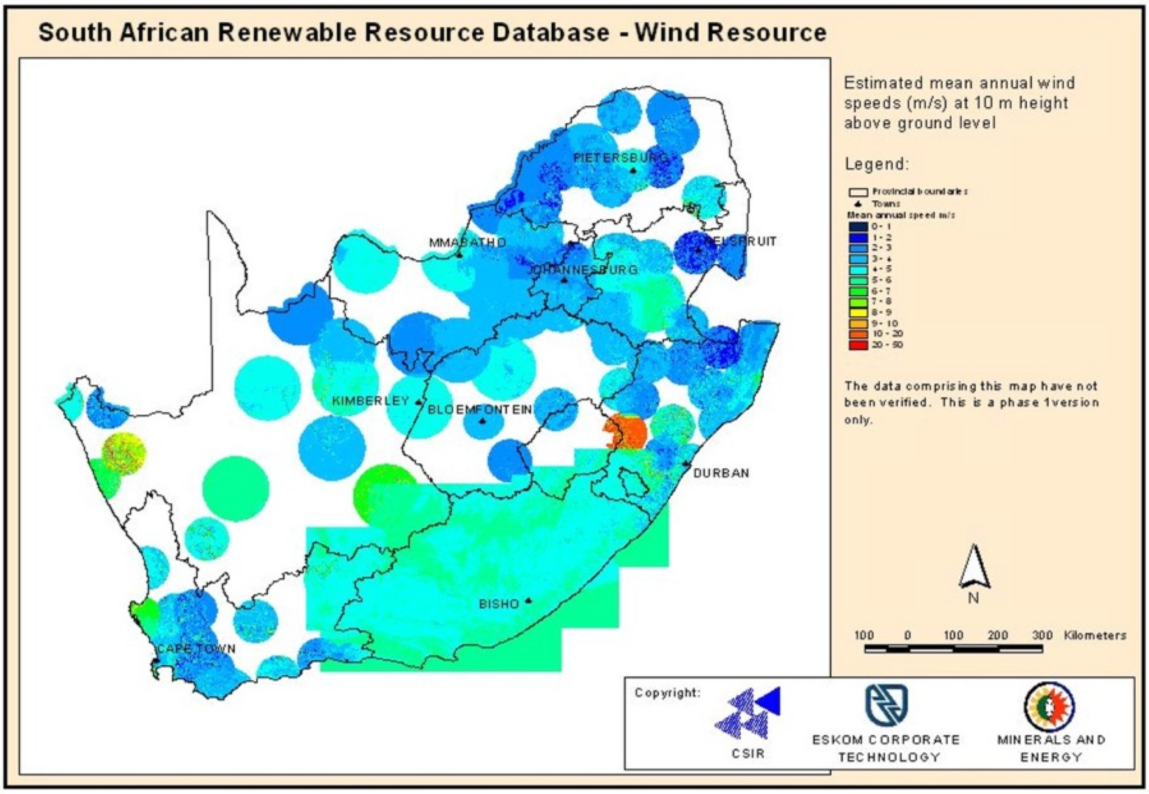
Source: Own computations

Graph 3: The impact of carbon credit revenue on the IRR values of the 1kW and 5kW turbines



Source: Own computations

Figure 1: Map of wind resources in South Africa



Source: DME et al. (2006)