

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

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Abstract

This paper investigates whether households and small businesses can voluntarily take advantage of the South Africa'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 used to displace electricity consumption from the grid is assessed by means of a financial analysis based on the internal rate of return method. The benefits of small-scale wind turbines output is valued at the grid power tariff which is saved rather than at the wind feed-in tariff rate. The analysis found the small-scale wind turbines to be robustly viable in locations with a mean annual wind speed of at least 8m/s, which is only a few of the windiest locations in South Africa. The competitiveness of the wind turbines is seriously challenged by the relatively low coal-based electricity tariffs in South Africa. As such, 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 between R1.00 and R1.60/kWh or a capital subsidy of between R25.95 and R32.330/kWh or a carbon credit price of between R2.135 and R3.200 will be needed to boost the viability of consumer-based small-scale wind turbines in areas with a mean annual wind speed of at least 5m/s, which is considered to be above average. Thus, 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 renewable energy expansion in the country. 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, while the significant funds required for capital subsidies might not be freely available. Carbon credit prices

have yet to mature to the required high levels. Thus, the removal of distortionary support to coal-based electricity generation might be the only currently available alternative of enhancing viability of consumer-based small-scale wind turbines.

Keywords: small-scale wind turbines, micro-generation, 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 38% of CO₂ emissions from fuel combustion in Africa and 1.1% of annual global emissions in 2008 (IEA, 2010). With the potential that a stricter post-Kyoto treaty calling for greater effort from 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. 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).

In order to quickly diversify the energy portfolio

and probably surpass the government target, South Africa should also be looking to consumer-based renewable energy technologies such as small-scale wind turbines.¹ Accordingly, this paper evaluates the financial viability of consumer-based small-scale wind turbines in South Africa with a view to determine the conditions under which households and enterprises will voluntarily adopt this technology. This is investigated for four scenarios, including three which take into consideration different financial support mechanisms that may be needed to facilitate adoption of this technology given cheap coal-based electricity.

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.

2. Background to wind availability and exploitation in South Africa

There have been two notable endeavours to assess nationwide wind resources in South Africa. 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 a renewable energy resource database with a more detailed range of mean annual wind speeds at a spatial scale of one square kilometre. The database 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 Drakensberg escarpment in the Eastern Cape and KwaZulu-Natal, wind speeds average in excess of 5m/s or 6m/s.²

Van der Linde and Sayigh (1999) forecast that South Africa could meet 5% to 6% of its energy demands with wind power – which corresponds to approximately 3 600 MW of installed capacity. The DME (2003b) suggests that the theoretical potential for wind energy harvesting in South Africa is approximately 26 000 GWh annually. However, the economically feasible annual production is calculated to be 0.23PJ (DME, 2004), equivalent to 1% of the country's electricity consumption, while Banks and Schäffler (2005) estimate the economically feasible output to be 0.38PJ, equivalent to 1.65% of the country's electricity consumption. The bottom line is that wind is a candidate renewable energy

source in South Africa and the spatial distribution of the wind resource will most likely be conducive to small-scale harvesting technologies. This is corroborated by Table 1, which illustrates the total installed capacity and estimated annual production for each of the different types of applications in South Africa (DME, 2003a).³

Table 1: Installed capacity and wind power production in South Africa

Source: DME (2003a)

Type	Capacity (kW)	Est. annual production (MWh)
National grid	3 160	5 000
Rural grid	45	111
Off grid	510	1117
Borehole windmill	12 000	26 000
Total exploited wind energy	15 715	32 228

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). The government has subsidized predominantly solar systems in a number of rural areas but this has 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; (ii) low operation and maintenance; (iii) more suitable to South Africa's windswept coastline where many areas without access to electricity are located; and (iv) significant storage potential (DME, 2003a).

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

The most prominent methods used to establish financial viability of small-scale wind turbines and other renewable energy technologies are the Payback Period and the Internal Rate of Return (IRR). The Payback Period method determines the period of time that the cumulative net revenue from an investment takes to equal the original investment. It is a crude method as it does not account for profits over the whole lifetime of the investment or the time value of money (Bannock et al., 2003).

The IRR method determines the discount rate which delivers a net present value of zero on the stream of net revenues of the investment (Spalding-Fecher, 2000). For the investment to be viable, the associated IRR has to be superior to the opportunity cost (i.e. return on an alternative investment) (White, 2005). This minimum expected rate of return is known as the hurdle rate or weighted average cost of capital (WACC).

The IRR is likely to be the more appropriate

framework for decision making by both households and small enterprises. Thus, in this paper, the IRR is preferred 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. Had we been only dealing with enterprises then the modified IRR would have been more suitable as it takes into account the fact that enterprises reinvest the returns earned during the lifetime of the investment at possibly variable rates.

4. Methodology

This paper investigates the financial viability of consumer-based small-scale wind turbines in the top ten windiest sites which formed part of the 98 sites where data was collected in South Africa by the 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; and Noupoot, Northern Cape. The analysis focuses on small-scale wind turbines for consumers who are grid-connected. While small scale wind turbines could have a design life of 20-40 years, this paper takes the lower bound as do other studies such as Dayan (2006).

The yearly benefit derived from a small-scale wind turbine is 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 applicable. In the absence of the last two components, 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.⁴

The hourly turbine harvest is given by the widely used power performance curve (Ackermann and Söder, 2000). The power performance curve is represented by the following formula:

$$P = \frac{1}{2}\rho AV^3 C_p \quad (1)$$

where P is the hourly 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 hourly power output is then multiplied by the number of hours in a year (i.e. 8 760 hours) 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. The area swept by the turbine's rotor blades is a function of the diameter of rotor blades. The observed rotor blades diameter tends to range from 2.5-3.0m for a 1kW turbine and 5.0-6.5m for a 5kW turbine. The analysis therefore assumes a 2.7m diameter for a 1kW turbine and a 6.0m diameter for a 5kW turbine.⁵ The annualized mean hourly wind speed data for the top ten windiest locations in South Africa observed by the CSIR et al. (1998) is used.⁶ Since small-scale wind turbines are able to achieve high rotor speeds a C_p mean value of 0.45 is assumed.⁷

In 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.⁸ REFITs are applicable for qualifying renewable energy generation facilities with a size greater or equal to 1 MW and are only paid for supplying electricity to the grid. In order to achieve economies of scale and a faster administration process, the preferred minimum size of the facility for the wind technology was set at greater than or equal to 20 MW. However, this paper only considers small-scale wind turbines of 1kW and 5kW hence REFITs do not affect the viability of consumer-based wind turbines considered here as they are only used to displace consumption of electricity from the grid rather than supply electricity to the grid. 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.

The tariff rates (i.e. energy charges per unit) used in the analysis are represented by the Business rate of 58.62c/kWh and the Homepower standard rate of 87.04c/kWh as charged by Eskom to non-municipal customers as of 1 April 2010 (Eskom, 2010).⁹ Although there is a plethora of factors¹⁰ which may influence the level of tariff adjustment in South Africa in the future, it is assumed that electricity tariffs will increase on average 10% per annum over the lifespan of the wind turbine.¹¹

It is assumed the initial capital investment is incurred in the initial period while the operation and maintenance costs are incurred in the remaining periods. The annual operation and maintenance costs are assumed to cover all monitoring, metering, repair, replacement, insurance, administration and any other fixed or variable costs incurred during the lifetime of the small-scale wind turbine. In a general model of this nature, we do not make any provision for depreciation.

Based on the 2009 average estimates for the South African small-scale wind turbine market, the value for initial capital investment is set at R45 000 for the 1kW turbine and R200 000 for the 5kW turbine.¹² 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 and therefore require more initial accessories. The annual operation and maintenance cost is assumed to be fixed at 1% of the initial capital investment throughout the turbine's lifetime (AWEA, 2007).

The IRR of a small-scale wind turbine is a function of the net benefit flows over the lifetime of the wind turbine. The financial viability analysis involves calculations of the IRRs for each site for a 1kW and a 5kW wind turbine in the following four policy scenarios:

- i) The market with standard electricity tariff rates, no capital subsidies and no financing from the sale of carbon credits (i.e. the status quo);
- ii) The market with a tariff subsidy on top of standard tariff rates, no capital subsidies and no financing from the sale of carbon credits;
- iii) The market with standard tariff rates, a capital subsidy and no financing from the sale of carbon credits;
- iv) The market with standard tariff rates, revenues from the sale of carbon credits and no capital subsidies.

5. Discussion of results

As discussed in section 3, the IRR for an investment needs to exceed the hurdle rate or WACC for it to be viable. The WACC can also be defined as the sum of the risk-free return on equity plus an equity risk premium (Kantor and Marchetti, 2005). The R157 Government bond is used as a proxy for the tax-adjusted risk-free return on equity in South Africa. The risk-free return on equity and equity risk premium were estimated to 9.325% and 5-5.5% in South Africa (Kantor and Marchetti, 2005). Therefore, a WACC of 15%, similar to that in the

equity market, was assumed after taking into consideration the uncertainty regarding future technologies and the general energy environment in South Africa.

5.1 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 mechanism. This implies that either the Business rate or Homepower rate tariff only is applied. Using the flow of net benefits associated with this scenario, the IRRs are computed in Microsoft Excel for the selected sites. These are given in Table 2 and the goal of the analysis is to determine the sites at which wind turbines are viable i.e. where the IRR surpasses the WACC of 15%.

The IRR for a 1kW turbine exceeds the hurdle rate at two locations when facing the Business rate and at four locations when facing the Homepower rate. Thus, the viability of a 1kW wind turbine is only robust at Gains Castle and Springbok. This turbine will yield exceptionally high returns (IRR of at least 63%) at Gains Castle on account of the extremely high wind speed at this location. The viability of a 5kW turbine is also robust only at Gains Castle and Springbok even though the IRR exceeds the hurdle rate at four other locations in the presence of the Homepower rate. A 5kW turbine situated at Gains Castle once again produces 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 small-scale wind turbines to be robustly viable at any location. Despite this evidence, some consumers, for instance, with a greater risk appetite or a reduced hurdle rate as a result of a lower cost of finance or facing much higher tariffs than assumed here, may be able to justify an investment at any location with a lower mean annual wind speed. Given that such consumers are likely to be in the minority, we con-

Table 2: IRR's for the 1kW and 5kW turbines at various locations

Source: Own computations

Site	Annual mean wind speed	IRR for 1kW turbine (58.62c/kWh)	IRR for 1kW turbine (87.04c/kWh)	IRR for 5kW turbine (58.62c/kWh)	IRR for 5kW turbine (87.04c/kWh)
Gains Castle	13.94	63%	89%	69%	98%
Springbok	8.27	18%	25%	20%	27%
De Aar	6.88	11%	16%	12%	17%
Langebaan	6.88	11%	16%	12%	17%
Simonstown	6.65	10%	14%	11%	16%
Cape Town	6.63	10%	14%	11%	16%
Koningnaas	6.20	8%	12%	9%	13%
Ixopo	5.82	6%	10%	7%	11%
Geelbek	5.62	5%	9%	6%	10%
Noupoort	5.60	5%	8%	6%	10%

clude that, in general, consumer-based wind turbines will not be voluntarily adopted in some locations with an annual mean wind speed of at least 5m/s, a wind resource satisfied by the 10 locations considered and which would generally be considered to be above average.

The competitiveness of the wind turbines is seriously challenged by the relatively low coal-based electricity tariffs in South Africa. Thus, the removal of distortionary support¹³ to coal-based electricity generation might be an alternative way of enhancing viability of consumer-based small-scale wind turbines. In the absence of the removal of such distortionary support, the government would have to pursue other policy options to facilitate the viability of consumer-based small-scale wind turbines in the other locations in South Africa. The remainder of this section considers different financial support mechanisms that may be needed to facilitate adoption of this technology given cheap coal-based electricity.

5.2 Results discussion for Scenario 2

This scenario investigates facilitation of adoption of a small-scale wind turbine through a tariff subsidy. 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.

This scenario analyzes the level of tariff subsidy required by a typical wind turbine owner in order to achieve the hurdle rate of 15%. We assume that the typical wind turbine owner is located at a location with an annual mean wind speed of 5m/s, a wind resource which would generally be considered to be above average.¹⁴ The relationship between the computed IRRs of the 1kW and 5kW turbines for the different levels of tariff subsidies can be presented in a similar way to Table 2 but they are presented here in Figure 1 and only for the case of the Business rate for brevity. For a 1kW turbine, a tariff subsidy of at least R1.20 would be needed to make the turbine viable in the presence of the Homepower rate while R1.60 would be needed in the presence of the Business rate. For a 5kW turbine, tariff subsidies of R1.00/kWh above the Homepower rate and R1.40 above the Business rate are required to overcome the hurdle rate.

The REFITs announced by NERSA in 2009 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. 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. 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 in the spirit of the Renewable

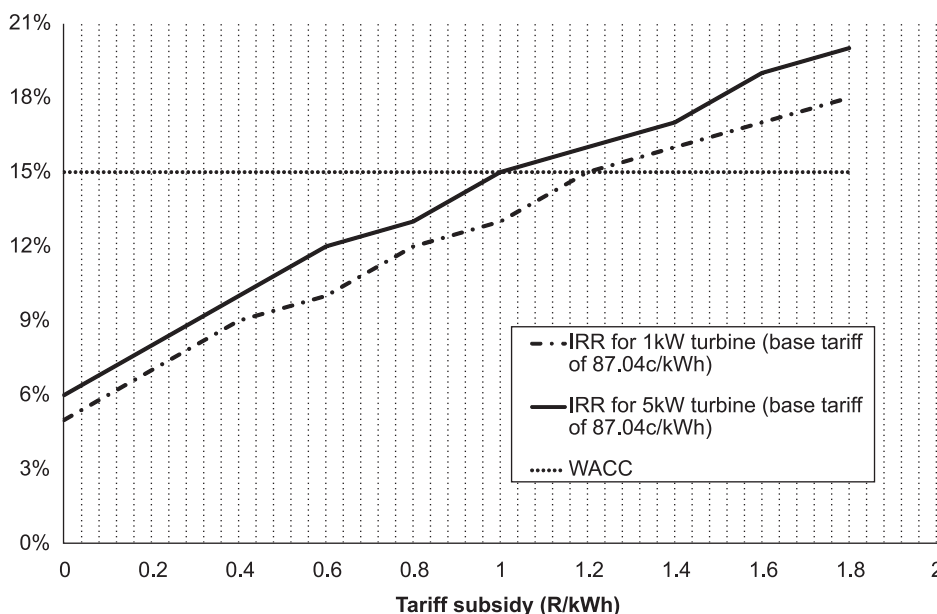


Figure 1: The impact of tariff subsidies on IRR values of the 1kW and 5kW turbines
Source: Own computations

Obligation Certificate programme implemented in the UK, among other countries (Bahaj et al., 2007).

The need for such huge subsidies to enhance the viability of small-scale wind turbines should not necessarily be a cause for budgetary concerns. 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.

5.3 Results discussion for Scenario 3

This scenario assesses the case where owners of small-scale wind turbines receive a capital subsidy. This capital subsidy might be a once-off receipt or may be divided up and received at various intervals over the lifetime of the turbine. In this scenario, it has been assumed that the full capital subsidy is received at the time of initial investment (i.e. in year 0). This scenario analyzes the level of capital subsidy required by owners of small-scale wind turbines located at a site with a mean annual wind speed of 5m/s in order to achieve the hurdle rate of 15%. The results of this analysis are depicted in Figure 2, which shows that for an increase in level of subsidization on the initial capital investment there is an exponential growth in the computed IRR for both turbine sizes. Capital subsidies of at least R32.170 and R25.950 are required by the owner of a 1kW turbine who faces the Business rate and Homepower rate respectively in order for small-scale wind turbines to be viable at a location with mean annual wind speed of 5m/s. The viability of a 5kW wind turbine requires capital subsidies of R32.330 per kW and R26.190 per kW installed capacity when

facing the Business rate and Homepower rate respectively.

The single most significant financial barrier for investors in small-scale wind turbines is the high initial capital investment required. 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. At present, South Africa has limited financial support for investment in renewable energy projects. Capital subsidies are available from the Renewable Energy Finance and Subsidy Office (REFSO), a subsidiary of the DME. Other subsidies can be secured through the Department of Trade and Industry (DTI). The Energy Development Corporation (EDC), an organ of the Central Energy Fund, provides equity, loans and expertise to viable renewable energy projects. However, all this support highlighted above is 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, 2008). 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. 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 current distortionary support to the power utility, Eskom.

5.4 Results discussion for Scenario 4

This final scenario investigates the case where a small-scale turbine owner with a turbine located at

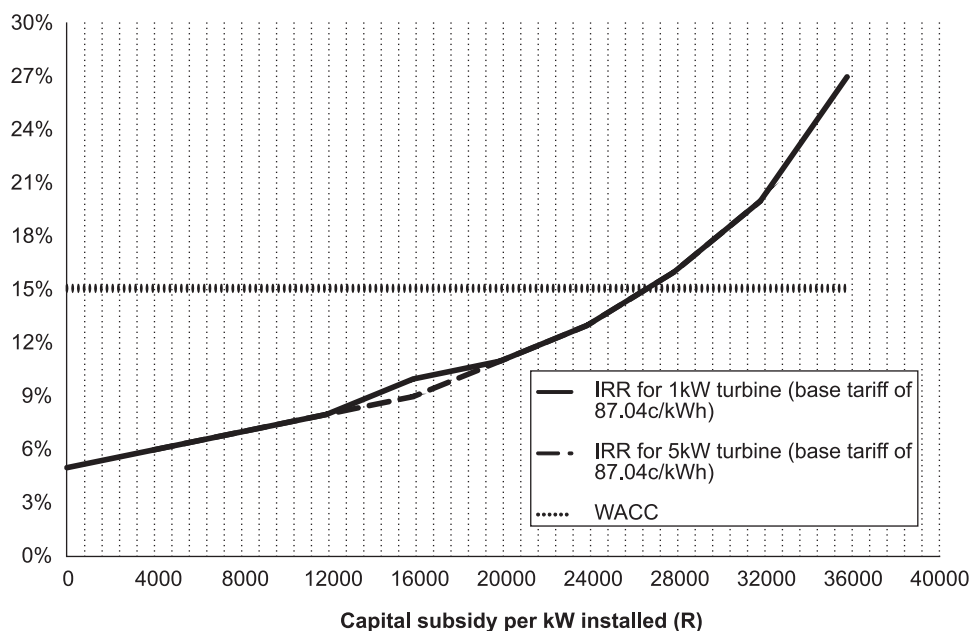


Figure 2: The impact of a capital subsidy on the IRR values of the 1kW and 5kW turbines
Source: Own computations

a site with a mean annual wind speed of 5m/s has secured a 20-year contract of sale for forward-priced carbon credits from a willing buyer in the carbon market. Renewable energy project developers in non-industrialized countries can access carbon credits through the clean development mechanism (CDM) or voluntary markets. The baseline emissions level for the area where the wind turbines will be installed will be assumed to be 0.000963 tons of CO₂/kWh. This is quite close to estimates by Zhou et al. (2009). The emissions levels for both the 1kW and 5kW turbines are zero. Thus, the total carbon savings from each wind turbine is 0.000963H where H is the amount of electricity to be generated during the turbine's lifetime. Similarly, the carbon revenue from the wind turbine is the product of the total carbon savings and the negotiated price of the carbon credit. It is assumed that there are no transaction costs¹⁵ 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. The results of the analysis are shown in Figure 3.

Carbon credit prices of at least R3.200 and R2.580 per tCO₂ saved by owners of 1kW turbines facing the Business rate and Homepower rate respectively and R2.750 and R2.135 per tCO₂ saved by owners of 5kW turbines facing the Business rate and Homepower rate respectively will be required in order for small-scale wind turbines to be viable at a location with mean annual wind speed of 5m/s. The reason such high carbon credit price would be required is because the annual avoided emissions of CO₂ for the small-scale wind turbines are relatively low and thus the revenues

from sales of carbon credits are outweighed by the large initial capital investment. The revenues generated from carbon credit sales, even at a carbon credit price of R400/tCO₂,¹⁶ a price at the very top end of the carbon credit market, will be insufficient to boost the IRRs for both a 1kW and 5kW turbine beyond the hurdle rate. 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. As small-scale wind turbine owners are unlikely to secure the high prices associated with the viability of wind turbines, especially given the uncertainty in the carbon credit market post-2012 when Kyoto expires, suggests that carbon financing will not be effective in boosting voluntary adoption of consumer-based small-scale wind turbines in the short to medium term.

6. Conclusion

The South African government aims to reach the medium-term target of 10 000GWh of additional renewable energy power by 2013. The wide-scale application of small-scale wind turbines can potentially make a significant contribution in assisting government meet this target. This paper has investigated whether households and small businesses can voluntarily 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 used to displace electricity consumption from the grid is assessed by means of a financial analysis based on the internal rate of return method. The benefits of small-scale wind turbines' output is valued at the

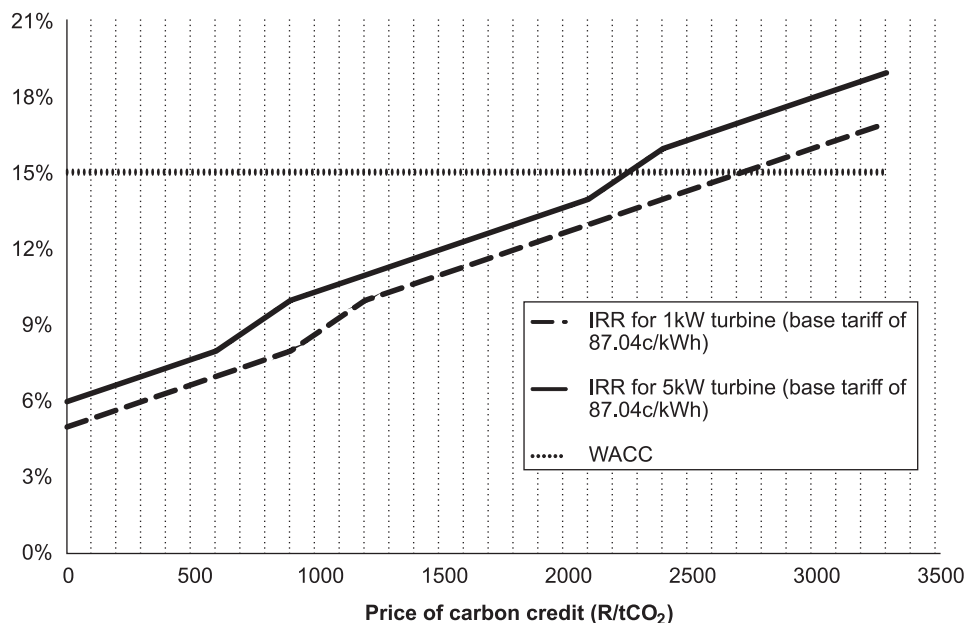


Figure 3: The impact of carbon credit revenue on the IRR values of the 1kW and 5kW turbines
Source: Own computations

grid power tariff which is saved rather than at the wind feed-in tariff rate.

Wind conditions are critical to the viability of small-scale wind turbines and this technology is likely to be a viable investment for voluntary adoption in locations with a mean annual wind speed of at least 8m/s. For the other locations, sufficient savings on avoided coal-based electricity will not be made. The competitiveness of the wind turbines is seriously challenged by the relatively low coal-based electricity tariffs in South Africa. The removal of distortionary support to coal-based electricity generation might be an alternative of enhancing viability of consumer-based small-scale wind turbines. In its absence, the wind turbines would have to be supported by financial mechanisms such as a tariff subsidy; a capital subsidy and revenue from carbon credits. The analysis reveals that a tariff subsidy of between R1.00 and R1.60/kWh or a capital subsidy of between R25.950 and R32.330/kW or a carbon credit price of between R2.135 and R3.200 will be needed to boost the viability of consumer-based small-scale wind turbines in areas with a mean annual wind speed of at least 5m/s, which is considered to be above average. 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, while the significant funds required for capital subsidies might not be freely available. Carbon credit prices have yet to mature to the required high levels. Thus, there is a need for (i) subsidizing all producers of renewable energy including those who produce it for their own consumption as they equally contribute to renewable energy expansion in the country or (ii) the removal of distortionary support to coal-based electricity generation. The latter might be the only currently available alternative of enhancing viability of consumer-based small-scale wind turbines.

Notes

1. This paper follows the categorization of Ackermann and Söder (2000) who regard a wind turbine with capacity under 10kW as small scale. To give an idea of what different scales of wind turbines can achieve, 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.
2. 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 (Schäffler, 2001; White, 2005).
3. Regrettably these statistics do not account for wind

turbines installed within the last seven years, such as those at the Darling Wind Farm.

4. The financial analysis assumes that transmission, voltage, network, service and other surcharges are fully reflected in the tariff.
5. The rotor area is πr^2 .
6. We have preferred to use mean annual wind speed in this analysis as more elaborate measures would have complicated the analysis considerably. However, the mean annual wind speed is an insufficient measure for determining the viability of a potential wind site. The Weibull distribution is a mathematical expression, which provides a good approximation to many measured wind speed distributions and is therefore frequently used to characterise a site. For more details, the reader is referred to: <http://www.wind-energy-the-facts.org/en/part-i-technology/chapter-2-wind-resource-estimation/local-wind-resource-assessment-and-energy-analysis/the-annual-variability-of-wind-speed.html>.
7. The maximum value of this variable is 0.59, known as the Betz limit.
8. On 26 March and 29 October 2009, NERSA approved REFITs Phases I and II respectively. On 19 February 2010, NERSA promulgated rules on selection criteria for renewable energy projects under the REFIT programme.
9. 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.
10. It should be noted that electricity prices in South Africa are closely tied to the coal and diesel price, which have been on the rise in the late 2000s (Eskom, 2008).
11. It should be noted that, in practice, tariffs might increase by more than 10% in some years but that will enhance the likelihood of them increasing by less than 10% in future time periods. The most important thing is that the cumulative increases over the lifetime of the wind turbines can be annualized to roughly 10%.
12. The figures include the cost of the wind turbine, tower, battery bank, inverter, standard accessories and installation. Note that the Capacity Building in Energy Efficiency and Renewable Energy 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).
13. An example of distortionary support for coal-based power utilities in South Africa would be (i) the equity injections that government makes into Eskom, (ii) the R60 billion subordinated loan that government is contributing towards Eskom's capital expansion programme and (iii) the multi-billion loan guarantees that the government has given Eskom e.g. for the \$3.75 billion loan from the World Bank to partly finance Medupi plant.
14. 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.

15. There can be a wide range of transaction costs involved in carbon credit trading such as monitoring, verification, registration, legal and administration costs.
16. The carbon credit prices range between R50-R400 in the markets (Genesis Analytics, 2008).

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