An Economic Evaluation of a Wind Power Electricity Generating Farm in South Africa

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Abstract

Renewable energy projects need to be evaluated from a social standpoint to determine their feasibility and attractiveness. Wind energy is a well developed and internationally traded technology that could present an opportunity to South Africa, because of the country's substantial wind resources. A 15 MW wind farm, located near Jeffreys Bay, Eastern Cape, has been proposed for development. There are indirect costs imposed on the local residents when a wind farm is established in their vicinity. A contingent valuation study was undertaken to determine the magnitude of these indirect costs for the residents of Wavecrest, Jeffreys Bay, the closest residential community to the proposed wind farm. A Logit regression was used to predict WTA for the wind farm project. The estimated WTA was determined to be R146.52/a per person, or R490'695.48/a in total. Benefits and costs were further investigated so that a comprehensive cost-benefit analysis could be undertaken. Using the direct and indirect costs and benefits presented, the cost-benefit analysis indicated that the wind farm was a socially desirable project, with a net present value of R 108 273 903.67 and a benefit-cost ratio of 1.512.

Keywords: Contingent Valuation, Cost Benefit Analysis, wind farm

1. Introduction

Over the past 40 years there has been recognition of the fact that human activity has reached a scale capable of influencing our environment (Davidson, 2005). Along with diminishing sources of known fossil fuel deposits, this growing environmental awareness has led to a search for alternative sources of energy, especially clean energies. There are a number of renewables currently receiving attention on the global stage, including wind, solar, thermal, hydro, biomass and tidal power. Technologies exist that are capable of creating electricity from all of these sources. Of all the potential renewable energy sources, wind energy has experienced the greatest growth worldwide over the past few years (Yue, Liu & Liou, 2001).

Although wind energy is a relatively well-established source of energy internationally, it has yet to penetrate the South African market, despite the potential due to South Africa's long coast line and abundant open areas. Opponents of wind energy argue that there are local negative externalities (or indirect costs) associated with the location of wind turbines, which include the potential deterioration of scenic views and the disturbing noise created by the rotation of the turbines (Warren, C. R., Lumsden, C., O'Dowd, S., & Birnie, R., 2005). These externalities fall into the broad problem known as a locally undesirable land use (LULU). In turn, these locally undesirable uses of land may lead to the not in my backyard syndrome (NIMBY). It is argued that this syndrome may lead to inefficient resource allocation because the costs of the negative externality are borne locally while the benefits are distributed more broadly (O'Hare, 1977). A possible solution to the problem is compensating those affected by the local externality. In a study conducted by Groothuis, Groothuis & Whitehead (2008) a measure of the compensation required to allow wind generation windmills to be built in the mountains of Watuaga County, North Carolina, USA was estimated. The results of the study indicate that an amount of $1.90 per month or $23 per annum per household was required for the project to go ahead. Based on an estimated18 540 households in Watuaga County, total compensation required equaled $426,400. These results indicate that people are willing to accept a reduction in scenic view quality due to the construction of a wind farm, provided they receive adequate compensation.

In order to evaluate the social desirability of a proposed project, it is necessary to examine all the costs and benefits associated with that project. The externalities mentioned above represent the indirect costs associated with a wind farm project. Along with these indirect costs, there are also direct costs, direct benefits and indirect benefits. By summing and discounting these cost and benefit flows over the life of the project, it is possible to determine whether or not the project represents an improvement in the social allocation of resources.

The development of a wind farm, by Genesis Eco-Energy (Pty) Ltd, in close proximity to Jeffrey's Bay, South Africa, may be viewed by some as a LULU. The project is located on the Sunnyside dairy farm approximately 5km from Jeffrey's Bay on the slope of a hill north of the N2 highway connecting Port Elizabeth and Cape Town. The closest inhabited residential area is a suburb of Jeffrey's Bay called Wavecrest (Lochner, P., Dippenaar, S., Wren, S., Binneman, J., Holland, H., Illgner, P., Van Rooyen, C., & Malherbe, F., 2008). The selection of appropriately sized wind turbines is still under consideration. It is expected that machines of 1.8 to 2 MW will be installed. One turbine size is expected to be used for the entire wind farm. The final choice of the size of turbine will be based on ease of erection, availability, suitability to the wind regime and flicker effects (Lochner *et al*., 2008). Table 1 below shows the details of the proposed project.

Table 1: Project Specification

CHARACTERISTIC	**VALUE**
Name	Kouga Wind Energy Project
Location	Sunnyside Dairy Farm, Jeffrey's Bay
Installed capacity	15MW
Project life	25 years
No. of turbines (turbine capacity)	8 (≈2MW) to 30(≈500kW)
Area required	20ha
Turbine height	75m
Blade length	45m
Annual capacity factor	30%
Electricity production	21462MWh
CO2 off-set	545000 tonnes

Source: Lochner *et al.*(2008)

The wind measurement studies undertaken at the site indicate kilowatt hours (kWh) production will be relatively equally distributed both daily and seasonally (Lochner *et al*., 2008). The wind turbines will be connected to the local Eskom grid via a new line (22kV capacity) of approximately 500m in length (maximum) which connect to the existing municipal power line of 66 kV that passes the eastern edge of the site. Certain sections of the existing power lines may require upgrades, but this will require only installing new conductors, not an entirely new line (Lochner *et al*., 2008). Should the existing lines not be able to carry all of the load, it may be necessary to run a new 66kV line from the site to the main Eskom 132kV line that joins from the Melkhout substation (Lochner *et al*., 2008).

The aim of this study was to provide the first formal attempt to quantify the compensation required to overcome the NIMBY syndrome associated with the establishment of a wind farm in South Africa; the specific wind farm being the one in Jeffrey's Bay, Eastern Cape. The compensation required is estimated by means of the contingent valuation method (CVM). Then, using this compensation as one component, evaluate the social desirability of the project through the use of cost benefit analysis.

2. Economic Theory

2.1 The Contingent Valuation Method

The contingent valuation method (CVM) has over time become one of the most often used non-market valuation techniques. The method employs either willingness-to-pay questions to elicit individuals' preferences for improvements in public goods or willingness-to-accept questions to elicit individuals' preferences for deteriorations in public goods (Mitchell and Carson, 1989). The Blue Ribbon Panel Report to the NOAA Panel on Contingent Valuation (CV) resolved that it is a reliable and useful technique (see Arrow *et al*., 1993). The report also provided guidelines for good CV practice.

One of four elicitation methods can be employed in CVM studies, namely bidding games, open ended questions, payment cards, and dichotomous choice questions. A bidding game entails suggesting higher (lower) and higher (lower) amounts to individuals until their maximum WTP or minimum WTA (a point estimate) is reached (Mitchell and

Carson, 1989: 99). An open ended question is one in which an individual is asked to state his/her maximum WTP or minimum WTA (no values are suggested in this case). The payment card method presents an individual with a range of values from which he/she is requested to select the one which contains his/her maximum WTP or minimum WTA. With the dichotomous choice format an individual is presented with a single payment/offer (WTP/WTA amount) to which he/she must either agree or disagree.
Once the WTP or WTA responses are collected, various parametric models (OLS, Tobit, Logit, Probit etc.) can be applied to estimate preference functions, which in turn are used to calculate expected WTP or WTA values.

The economic theory underlying the application of the willingness-to-accept framework to the establishment of a wind farm can be explained as follows: assume a resident has the following utility function, utility = u(x(q), z), where z represents a consumption good and x(q) represents quality of a scenic amenity that can be affected by the presence of wind turbines. This resident maximizes his or her utility subject to a budget constraint y = px + z (where the price of z is normalized to one). Solving for the indirect utility function yields v(p, q, y) where y is income and p represents the price of the scenic amenity (Groothuis *et al*., 2008). The WTA for a reduction in the quality of the scenic view amenity can be ascertained when

$$v(p^o, q^o, y) = v(p^o, q^1, y + WTA), \quad (1)$$

where p^o is the current price, q^o is the original amenity quality and q^1 is the lowered amenity quality, and WTA is the willingness to accept welfare measure for lowering the quality of the scenic amenity (Groothuis *et al*., 2008).

2.2 Cost-benefit analysis

Cost-benefit analysis (CBA) is a project evaluation tool. The main aim is to sum up the present value of direct and indirect costs and benefits of a specific project to determine the social desirability of that project (Field, 2002). If the benefits are greater than the costs, then the project is considered to be improvement in society's allocation of resources. Having determined the main impacts, both positive and negative, from the proposed wind farm near Jeffreys Bay and then monetising those impacts, it is possible to conduct the CBA. The monetary values for the impacts need to be discounted first. The reason is that the cash flows (both incoming and outgoing) occur at different stages of the project and over the life-span of the project. Thus, it is necessary to determine the present value of the future expenses and revenues before summation.

The discounting of cash flows is an important step in the CBA. One reason is that the time preference of most individuals favour rewards now, which implies R1 now is worth more than R1 in a year's time. The determination of the social discount rate is a controversial topic because of the assumptions associated with the various rates. A discount rate of 3% was used, calculated as the difference between the Eskom bond rate and the consumer price index (CPI).

3. Survey design

3.1 Questionnaire development

The most important task in conducting a CVM study is the design of the questionnaire. With this in mind, every attempt was made to adhere to the guidelines recommended in the Arrow *et al*. (1993) report. These attempts are described below.

The survey was conducted via personal interviews and the pre-coded questionnaire, used as the survey instrument, was pre-tested by members of the research team. The questionnaire was subsequently refined and improved. A scenario was formulated to make the respondents aware of the effects of the proposed wind turbines. An accurate description of the project was presented to respondents and photographs of existing turbines were shown to the respondents. These photographs were pre-tested by members of the research team. The valuation question was posed as a vote on a referendum. More specifically, respondents were asked whether or not they would accept the establishment of the wind farm on the designated site in return for the specified compensation offer. Different WTA offer amounts were used, as “it is crucial that the arbitrarily assigned sums be varied across respondents” (Cameron, 1987). The contingent valuation question in the survey was:

> “Suppose to compensate individuals for accepting the wind farm in their area, electricity bills would be reduced by R XXX each month per household. Suppose this proposal is on the next election ballot. How would you vote on this proposal?”
>
> YES/NO

The R amount was randomly filled in with one of 6 rand amounts (R1, R5, R15, R30, R50 and R75). Following the status quo approach, all “Don’t Know” responses were treated as “No” responses (Groothuis *et al*., 2008).

Although it has been well documented that the WTP framework is the preferred format in CVM studies, the WTA elicitation method was employed in this study, given the perceived property rights of individuals in this particular context (Groothuis *et al*., 2008). It has been suggested by Inhaber (1992) that due to a reluctance to infringe on perceived property rights (based on politicians’ concerns about remaining in office) the status quo becomes the default property right when choosing a project’s location that will give rise to the NIMBY syndrome. WTA thus becomes the appropriate measure when individuals perceive that the status quo defines the property rights (Groothuis, *et al*., 2008).

A follow-up question was included in the questionnaire in order to determine the reasons for all “no” responses. Non-responses to the WTA question were zero.

3.2 Data collection

Sufficient research funds were available to allow for a sample of 180 respondents, representing 5.4% of the target population, to be interviewed face-to-face during the period January 2010 to March 2010. The sample frame consisted of residents of the Wavecrest suburb (Jeffrey’s Bay) situated in close proximity to the proposed site and who would thus be directly exposed to the wind farm. There are 4348 plots in the Wavecrest suburb of which 3349 are registered as developed plots. A representative sample of this population was chosen. The sample size for this population was determined by employing the following formula:

$$n = \frac{N}{1+N.e^2} \quad (2)$$

where:
n = sample size
N = population size
e = level of precision

Using the formula in Equation (2), the sample size was determined with a level of precision of 7.25%. This level of precision ensures a representative sample from the population, because the generally accepted level of precision for representative samples is 10% or less (Fink, 2003).

4. Statistical results and discussion

4.1 Socio-economic, behavioural and attitudinal analysis of respondents

Table 2 below provides a summary of the socio-economic profiles of the sample of households who were interviewed as part of the questionnaire survey.

Table 2: Socio-economic profile of respondents

Variable	**Mean**
Age (years)	59
Education (years)	12.85
Number of children	2.25
Household size	2.73
Retired (%)	53.89
Employed (%)	30.56
Resident (years)	8.95
Monthly electricity bill (Rand)	490.37
Gross annual income (Rand)	131 889.89

The average age of the respondent was 59 years. The average level of education for the respondents was 12.85 years. The average household size was 2.73 individuals and the average number of children per household was 2.25. The average respondent lived in Jeffrey's Bay for 8.95 years. Of the respondents, 53.9% indicated they were retired, whilst 30.56% were formally employed. The average income of respondents was R131 889.88, whilst the average monthly expenditure on electricity was R490.37 per household.

The questionnaire also included certain key questions which allowed an analysis of the respondents' behaviour and attitude towards the proposed wind farm project (see Table 3 below).

Table 3: Behavioural and attitudinal profile of respondents

Behaviour/attitude	% of respondents
Aware of project	72.78%
Subscription to scientific/environmental publication	6.67%
Member of environmental organization	2.22%
Member of outdoor organization	5.56%
Renewables should be government priority	99.44%
Concern about dependency on fossil fuels	83.89%
Concern about climate change	84.44%
Concern about wind turbines' harm to views	20.56%

The majority of respondents (72.8%) indicated that they were aware of the project. Subscription to environmental and scientific publications was low (6.7%) among respondents. The levels of involvement with environmental organisations (conservation and protection groups, etc.) were very low - 2.2% of respondents were members of such organisations. Involvement with outdoor organisations (fishing, hiking and surfing clubs) were higher, but still not very prevalent (5.5% of respondents). Support for renewable energies was substantial (99.4%), whilst 83.9% of the respondents indicated that dependency on fossil fuels was a concern. Of the respondents, 84.4% indicated that climate change was a concern. Concern for the impacts on the views of area due to the establishment of a wind farm was limited (20.6%).

4.2 An analysis of WTA responses

Table 4 below reports the number and percentage of "yes" responses at each offer amount. At the lowest rand amounts, 86.67% indicated they would accept the offer. As can be expected, the percentage of "yes" responses increases as the offer amount increases.

Table 4: Responses at each offer amount

Offer amount	Yes	No	%Yes
R1	26	4	86.67%
R5	26	4	86.67%
R15	27	3	90%
R30	28	2	93.33%
R50	29	1	96.67%
R75	30	0	100%

4.3 Statistical model of WTA

Due to the referendum format of the WTA question where a respondent simply votes "yes" or "no" to a single Rand amount, the probability they would accept a given Rand amount is statistically estimated by means of a qualitative choice model such as a Logit model.

The Logit model can be expressed more formally as:

$$\text{Probability (Yes)} = 1/(1 + e^{-\beta' X}) \qquad (3)$$

where $\beta' X_i = \beta_0 + \beta_1 X_i$.

The β's are coefficients to be estimated using the Logit statistical technique and the independent variable, X_i, is the Rand amount the household was asked to accept. Independent (explanatory) variables could include the WTA amount only or could include the WTA amount and a combination of socio-economic, behavioural and attitudinal variables. Logit models make use of maximum likelihood criterion in estimation procedures, as opposed to the ordinary least squares criterion (Gujarati, 2003).

Fourteen independent variables were originally included in the Logit model (Dimitripoulos & Kontolean, 2009; Groothuis *et al*., 2008; Ladenburg, 2008; Kondouri, Kountouris and Remoundo, 2009). These were: age of respondent, years of education of respondent, number of children, household size, whether the respondent was a retiree, whether the respondent was employed, years the respondent had been a resident in the town, average monthly electricity bill, gross annual income, awareness of the project, concern about fossil fuel dependence, concern about climate change, concern about view shed impacts and the WTA offer amount.

A complete statistical model inclusive of all the abovementioned attitudinal, behavioural and socio-economic variables was initially estimated. Following an inspection of statistically significant coefficients, a more parsimonious model (the reduced model) was estimated. The following coefficients were insignificant and were excluded from the final model: age of respondent, years of education of respondent, number of children, household size, whether the respondent was employed, years the respondent had been a resident in the town, average monthly electricity bill, gross annual income, awareness of the project and concern about fossil fuel dependence.

The reduced statistical model estimated was:

$[\log(\text{yes})/(1-\text{yes})] = \beta_0 + \beta_1(\text{RETIRED}) + \beta_2(\text{CLIMATE CHANGE}) + \beta_3(\text{VIEW IMPACT}) + \beta_4\log(\text{OFFER})$ (4)

where "yes" is the dependent variable and shows whether a person was or was not willing to accept the amount offered during the questionnaire survey. A yes vote was recorded with a 1, and a no vote with a 0.

In the interests of conserving space, only the reduced model with coefficients significant at the 90% level or better is displayed (see Table 5 below).

Table 5: Logit regression model of probability would accept compensation

Variable	**Coefficient**	**z-Statistic**	**Median**
Constant	0.571764	0.510038	
Retired	1.809932	2.163313**	1
Concern about climate change	2.124368	2.417749**	1
Concern about view impact	-4.354802	-4.326954***	0
Log of offer amount	1.800294	2.782895***	1.326606257
McFadden R^2	0.492090		

** Significant at the 0.05 level
*** Significant at the 0.01 level

The statistically significant coefficients can be interpreted as follows:

- Retired: The retired variable's coefficient is statistically significant at the 5% level. The positive sign indicates that if the respondent is retired he or she would be more likely to accept the compensation offered for the project to go ahead.
- Concern about climate change: This variable's coefficient is positive and statistically significant at the 5% level. This means that if the respondent is concerned about climate change he or she would be more likely to agree to accept the compensation offered for the project to go ahead.
- Concern about view impact: The coefficient of this variable is statistically significant at the 1% level and its negative sign suggests that if the respondent is concerned about the impact of the wind turbines on views, he or she would be less likely to accept the compensation offered for the project to go ahead.
- Offer amount: The positive sign of this coefficient suggests that the respondent would be more likely to vote in favour of the project at higher offer amounts. The coefficient is statistically significant at the 1% level.

4.4 Median and total WTA estimates

From Equation (3), Cameron (1987) provides a formula to calculate the median WTA. The formula is:

$$\text{Median WTA} = \exp^{(\beta_o/\beta_1)} \qquad (5)$$

where β_1 is the coefficient on the offer amount and β_0 is the grand constant calculated as the sum of the estimated constant plus the product of the other explanatory variables times their respective median values.

Using the formula in Equation (5), median WTA per household was estimated at R12.21 per month or R146.52 per annum. To calculate the total indirect cost to the Wavecrest population of the establishment of a wind farm, the median household WTA estimate was multiplied by the number of households in Wavecrest (3349). The total monthly indirect cost associated with the project is R40,891.29, which translates into an annual figure of R490, 695.48. The aggregate WTA estimation, however, constitutes only a partial analysis of cost. The capital, operating and maintenance costs of the wind farm project along with the indirect cost estimated in this paper need to be analyzed and compared with the total benefit (financial and environmental) estimates if adequate holistic decision-making is to take place. More specifically, the aggregate WTA estimated in this study must be viewed as only one cost input into a comprehensive social cost-benefit analysis to determine the desirability of wind farms for wider society.

4.5 Social costs and benefits

The impacts of the wind farm were examined and monetary values were attached where possible to determine the social desirability of the wind farm (Moran and Sherrington, 2006). The direct benefits were output revenues, fuel costs avoided, avoided GDP losses and extra water availability. The indirect benefit was the CO_2 emissions avoided. A summary of these benefits is provided in Table 6 below.

Table 6: Summary of social benefits

Social benefit category	Estimate
Direct benefits	
Output revenues	R12’447’960/a
Fuel costs avoided	R2’752’502/a
Avoided GDP losses	R29’347’826
Extra water availability	R287’025/a
Indirect benefits	
CO_2 emission avoided	R1’213’170/a

The direct costs were capital investment, operation and maintenance, extra balancing costs to the grid and rental cost of land (Moran and Sherrington, 2006). The indirect cost was taken from the CV study, using the median WTA estimate determined previously. The direct cost of extra balancing costs to the grid represents expected downturns in production due to wind intermittency (Moran and Sherrington, 2006). A summary of the costs associated with the proposed wind farm project are presented below in Table 7.

Table 7: Summary of social costs

Social cost category	Estimate
Direct costs	
Capital investment	R131’553’000
Operation and maintenance	R3’525’000/a
Extra balancing costs to the grid	R216’420/a
Rental cost of land	R337’500/a
Indirect costs	
WTA estimate	R490’695/a

Using these cost and benefit estimates, a cost-benefit analysis (CBA) was undertaken. The aim of this CBA was to determine whether the proposed wind farm project near Jeffreys Bay represents a socially attractive project. Using a discount rate of 3% and a project lifespan of 25 years, the costs and benefits were discounted and summed. The results of the CBA are summarised in Table 8 below.

Table 8: Summary of CBA decision criteria

Proposed Kouga Wind Energy Project: Jeffreys Bay	**CBA criteria (at social discount rate of 3%)**		
	NPV	**IRR**	**BCR**
	R108’273’903.67	11%	1.512

The net present value (NPV) is positive and large. The internal rate of return (IRR) is greater than the discount rate. The benefit cost ratio (BCR) is greater than 1. Therefore, according to the CBA decision criteria, the proposed wind farm project is a socially desirable allocation of resources that should be pursued. A sensitivity analysis undertaken on the data indicated that the results were robust in their support for the project.

5. Conclusion

The premise of the CV study was that individuals who are negatively affected by the local externalities caused by wind turbines are willing to accept compensation in the form of lower electricity costs. This compensation could play a role in helping to eliminate the not in my backyard (NIMBY) syndrome. This paper estimates the aggregate WTA (compensation) for the construction of a wind farm in close proximity to Jeffrey's Bay, South Africa to be R490,695.48 per annum. The study also shows that individuals' WTA is mainly influenced by two factors, namely concerns about climate change and concerns about view shed impacts. The results suggest that individuals who are concerned about climate change have less of a NIMBY reaction to view shed impacts compared to individuals who are not as concerned about climate change. Respondents, who are retired, are more likely to vote in favour of wind powered electricity. This estimate represents the indirect cost in a wider CBA.

The direct and indirect costs and benefits of the Jeffreys Bay wind farm project were presented and analysed. Based on the monetized impacts presented, it was determined that the project had a NPV of R108'273'903.67 with an IRR of 11% and a BCR of 1.512. This indicates that the project is a desirable allocation of social resources and should be pursued. A sensitivity analysis indicated the results were robust. Therefore, according to this research, the proposed wind farm is a worthwhile project.

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