

Wind Energy Conversion Systems:

A FEASIBILITY REPORT FOR MT GREY, NORTH CANTERBURY

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ABSTRACT

This report investigates the feasibility of Wind Energy Conversion Systems (WECS) on the Mt Grey ridgeline, 15km west of Amberley, in North Canterbury. The feasibility of wind generation at the site is studied in terms of electricity productivity and income, economic cost of energy and environmental impact.

Energy productivity and income at the Mt Grey site is estimated using data from two neighbouring climate stations at Ashley forest (distance 7km) and Balmoral (distance 33km). The annual energy production (in 2000) from a hypothetical 660 kW turbine is 2270 MWh. The average electricity price earned from generation at Mt Grey on the spot market is 3.52 cents per kWh.

The proposed site at Mt Grey would consist of 5 turbines having a rated power output of 3.3 MW and produce approximately 11.4 GWh of electricity per annum. The total capital costs of \$5.1 million and annual operating costs of \$58,500 are input into a discounted cash flow analysis with a standard EPRI-TAG annuitisation value of .1079. Cost of energy is calculated to be 5.4 cents per kWh.

In terms of environmental impact, Mt Grey is situated on a very prominent ridgeline in an area of scenic natural beauty, though there is already some disturbance at the site. A wind farm, though it will have little direct environmental impact, may disrupt the 'natural character' of the location. This question can only be answered by public debate within the framework of the resource management act.

TABLE OF CONTENTS

ABSTRACT.....	2
TABLE OF CONTENTS.....	3
1. INTRODUCTION.....	4
1.1. Overview.....	4
1.2. Project objectives.....	4
1.3. Data collection and collation.....	5
2. PRODUCTIVITY AND INCOME ANALYSIS.....	6
2.1. Methodology.....	6
2.2. Daily trends.....	8
2.3. Annual trends.....	8
3. ECONOMIC FEASIBILITY.....	11
3.1. Methodology.....	11
3.2. Cost of energy.....	12
3.3. Feasibility.....	12
4. ENVIRONMENTAL ASSESSMENT.....	15
4.1. Consents and permission.....	15
4.2. Impact assessment.....	15
4.3. The 'natural character' debate.....	15
5. WIND RESOURCE ANALYSIS.....	16
5.1. Wind direction analysis.....	16
6. CONCLUSIONS.....	18
7. FURTHER STUDY.....	19
ACKNOWLEDGEMENTS.....	20
REFERENCES.....	21

1. INTRODUCTION

1.1. Overview

The wind is a free, non-polluting and renewable resource. Wind is the movement of air caused by pressure differences as the sun heats the Earth's surface. The energy of wind has been harnessed since the 8th century A.D. in Persia (Smyth, 1987). Uses have included pumping water, milling grain and motive power for ships. The current interest in wind energy stems from its decreasing costs for the clean generation of electricity.

New Zealand's total electricity supply (StatisticsNZ, 2001) is 30,000 GWh per year, dominated by hydro (about 67 percent in 1997) and natural gas (22 percent in 1997). Currently wind energy provides approximately 0.5% of this electricity or around 150 GWh per year (EECA, 2001). This wind generating capacity comes from two wind farms sited at Haunui and Tararua.

The Haunui farm, owned by Wairarapa Electricity, consists of seven Enercon E-40 turbines mounted at a height of 44m above the ground and rated at 500kW each. The site, which began generating in May 1996, produces 13 GWh of electricity annually, enough power for around 1500 homes (Current, 1996). Total development costs were \$8.8 million (EECA, 1997).

The Tararua wind farm is a grander project consisting of 48 (soon to be expanded to 103) Vestas 660kW v47 turbines. With a rated output of 32MW, it currently produces 137 GWh of electricity per year and cost \$50 million to develop (NZWEA, 1999).

These two projects may be just the first in a succession of new wind energy developments in New Zealand in the next decade. This project aims to determine the current economic and environmental feasibility of wind development in the North Canterbury area, in particular at a site on the Mt Grey ridgeline 15km west of Amberley.

1.2. Project objectives

In this study I attempt to answer three specific objectives relating to the feasibility of the Mt Grey site for wind farming:

1. To estimate the quantity of electricity produced by a wind turbine in North Canterbury and the income earned from that electricity. Use the result to estimate the annual income and the price earned for electricity generation on Mt Grey.
2. To estimate the economic costs of constructing and operating a wind farm on the Mt Grey ridgeline using a standard cost of energy analysis and use these results to ascertain the economic feasibility of the site.
3. To examine the environmental impacts of developing the Mt Grey wind farm, and possibilities for mitigating these effects.

Additionally, I have made a general analysis of certain aspects of the wind resource in the North Canterbury region. In particular I assessed:

- The extent to which the wind resource matches patterns of electricity demand. It has been suggested that the wind tends to blow more strongly in the afternoon when electricity demand is higher (Anderson, 1996). Also higher seasonal winds occur during the winter when hydro lakes are at their lowest (Anderson, 1996).
- The directional variation of wind in North Canterbury in order to verify the assertion that Canterbury has predominantly Norwest and Southerly winds.

1.3. Data collection and collation

The National Rural Fire Authority (NRFA) runs a national network of over 150 remote automatic weather stations, sixteen of which are in Canterbury. I obtained data from two NRFA climate stations, at Ashley forest (distance to Mt Grey 7km) and Balmoral (distance to Mt Grey 33km). This data is a record of hourly mean wind speed and direction and covers the nineteen-month period from 1 August 1999 until 28 February 2001. The anemometers used to record this data are placed at standard meteorological AGL (above ground level) height of 10 metres.

The market company "m-co", which runs the New Zealand electricity market, provides half hourly 'spot' market reference prices in excel format from their website at <http://www.m-co.nz>. The data obtained covers the period from 1 August 1999 until 30 June 2001.

In order to assess wind speeds on Mt Grey I installed an automatic weather station and data logger near the peak trig station (altitude 934m). Data was recorded at height of 3m between August 1, 16:40 and August 4, 15:00 at the 10 minute interval required for commercial wind farm assessments. The mean wind speed and direction was recorded and the instantaneous maximum and minimum speeds for the period were also recorded.

Turbine "power curve" data showing the power output from several commercial turbines at different mean wind speeds was obtained from the Danish Wind Turbine Manufacturers association website at <http://www.windpower.org>.

The data was integrated into an Access database to ensure data integrity and facilitate comparison. Software was developed to perform wind energy pricing model developed in this project.

2. PRODUCTIVITY AND INCOME ANALYSIS

A traditional wind turbine productivity and income analysis for a site is based on mean annual wind speed (Krohn, 2001). The calculation involves using the Weibull distribution, a plot of wind speeds versus frequency of their occurrence (Smyth, 1987).

The Weibull distribution is initialised with a site's mean wind speed and a 'shape' parameter representing the variability of the wind at that location (Krohn, 2001). The Weibull distribution is then combined with the turbine power curve, showing the turbine power output at each wind speed, to give total annual power output (Krohn, 2001).

2.1. Methodology

In this report I have developed an alternate, more direct method of calculating income from wind turbines based on hour by hour comparison between wind speeds, turbine power output and electricity spot prices on the New Zealand market. The spot market was formed in 1996. Its goals were to coordinate short-term electricity supply and demand, establish a least-price merit order for "dispatchable" generation and to establish a reference price for financial contracts and spot sales and purchases (WEMG, 1994).

The primary advantage with this method is that it takes into account the fact that wind varies and demand (price) varies but they may or may not vary in the same way. In the limiting case it is possible that all wind energy will be generated in one section of the day and all demand will be in another. In such a situation the traditional method based on annual mean wind speeds and electricity prices will be less valid. As we shall see in the economic feasibility section the difference between these two methods is significant.

A further advantage to this method is that it correlates directly with real-world operation of the electricity industry and the generation site. This makes it easier to convince potential investors of the validity of the model. Also, although the method is very data intensive it is relatively simple to perform and explain the calculation.

Adjusting wind speed

Mean wind speed data from anemometer readings are usually taken at a much lower height than a wind turbine's hub. Therefore, wind speeds must be approximated to turbine hub height using the following power law relationship (Cherry, 1976).

$$hubspeed \approx anemometerspeed \times \left(\frac{hubheight}{anemometerheight} \right)^\alpha$$

The exponent alpha is the terrain roughness factor and approximates the drag exerted by the surface on the air passing over it. A rough surface such as a forest may have a roughness factor of .40 while a smooth surface such as the ocean will have a roughness factor close to zero. Note that this method becomes increasingly less accurate in complex and mountainous terrain and may not be valid if performed on actual Mt Grey data.

For the purposes of this calculation I have used a roughness factor of alpha = 0.16. This value equates to open grassland with few trees or obstacles (Cherry, 1976). I have made the assumption that roughness is the same in each direction.

Turbine hub heights are optimised by economics. The optimum hub height is found by trading off between the costs of each additional metre of tower height versus the additional energy generation from the increased wind speed (Krohn, 2001).

Hub height optimisation is beyond the scope of this report. For this calculation I have used hub heights equal to rotor diameter of 47m. Aesthetically, many people find that turbines are more pleasant to look at in these proportions (Krohn, 2001).

Turbine power output

Mean adjusted hourly wind speed readings are now correlated with the power curve for the chosen turbine to produce the power output. Wind speed readings below turbine cut-in speed and above turbine cutout speeds do not contribute to energy output and are not included.

Wind speed readings within one ms^{-1} above cut-in speed are not included in these calculations in order to account for turbine startup and shutdown as the wind fluctuates above and below the cut-in speed.

Wind speed readings within one ms^{-1} below turbine cut-out speed are taken to produce half the predicted power output in order to account for turbine startup and shutdown as the wind fluctuates above and below the cut-out speed.

Income from wind energy

Finally, turbine power output is now correlated with prices from the New Zealand wholesale electricity spot market to produce the wind energy income for the hour.

The wholesale price of electricity is set independently at each of the 240 entry and exit points to the national grid (owned and operated by Transpower) each half hour throughout the day. The market company (M-CO) provide reference prices for two grid injection points, one at Benmore and the other at Haywards. The grid injection point nearest Mt Grey will vary slightly in price from the Benmore reference price used in this project. This is due to lines losses (called the AC loss factor) between different points in the national grid (Dr Chris Arnold, pers. comm).

The model was run using the Ashley forest and Balmoral wind data for the twelve-month period from January 2000 to December 2000 inclusive. The Vestas v47 turbine at a hub height of 47m was used.

2.2. Daily trends

Daily electricity generation (Figure 1) was very consistent across both sites and shows a distinct pattern of higher generation between 11:00 and 17:00 hours. Peak energy production in the late afternoon averages more than twice the early morning production.

Reference electricity prices show sharp peaks between 7:00 and 9:00 hours and again between 17:00 and 20:00 hours. Wind energy is at a minimum during peak morning demand but coincides quite well with peak early evening demand.

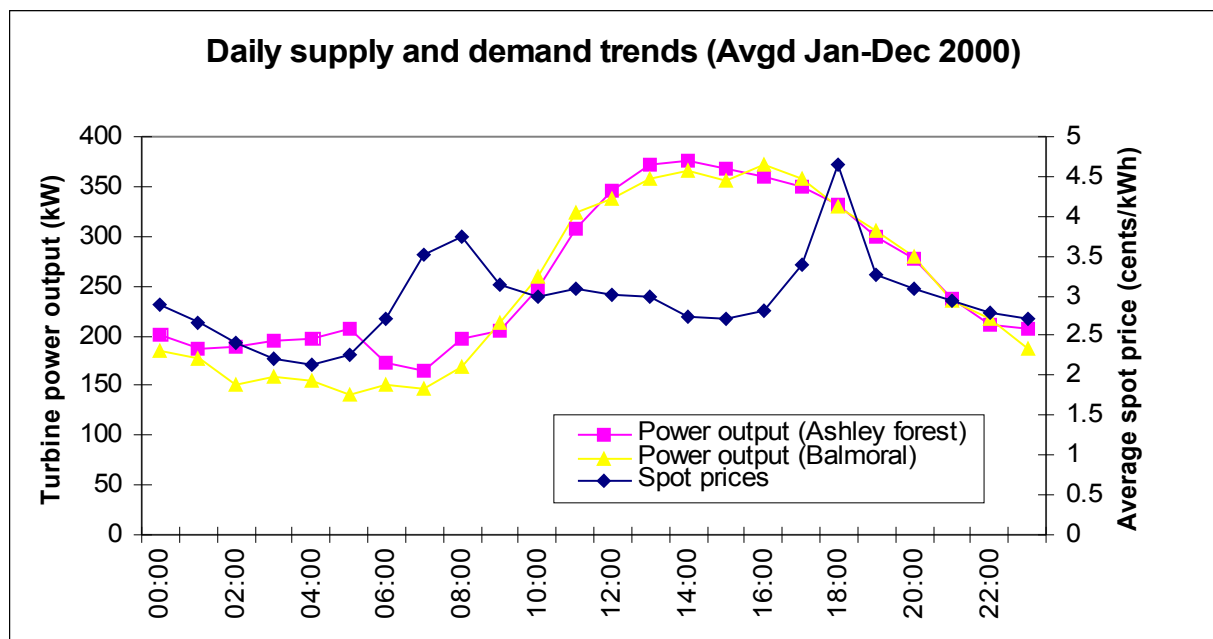


Figure 1. Graph of daily output from the model for the two NRFA weather stations

2.3. Annual trends

The trends in annual wind energy production are not quite as clear as the daily results as only a single complete year of data was available for analysis. However it is possible to draw some tentative conclusions. The strong drop in energy output in July and August would seem to suggest the months represent annual minimum for New Zealand. Mean wind recordings from other sites around Canterbury (Cherry, 1976) support this. Generalisations must be made carefully however as there are some sites such as Wellington where this does not appear to be the case (Cherry, 1976).

Unfortunately, it seems likely low hydro inflow in mid-winter may coincide with low wind speeds in Canterbury in June and August. However, if the peak in wind energy in September and October proves to be a consistent phenomenon then this may compliment low hydro supply in late winter.

The other interesting conclusion that can be drawn from this graph is that annual wind energy variations are more dramatic between sites than daily variation. Balmoral is consistently generating more energy than Ashley in autumn and Ashley consistently generates more electricity in winter and spring. It could be related to a change in predominant wind direction between seasons, a phenomenon I haven't considered in this report.

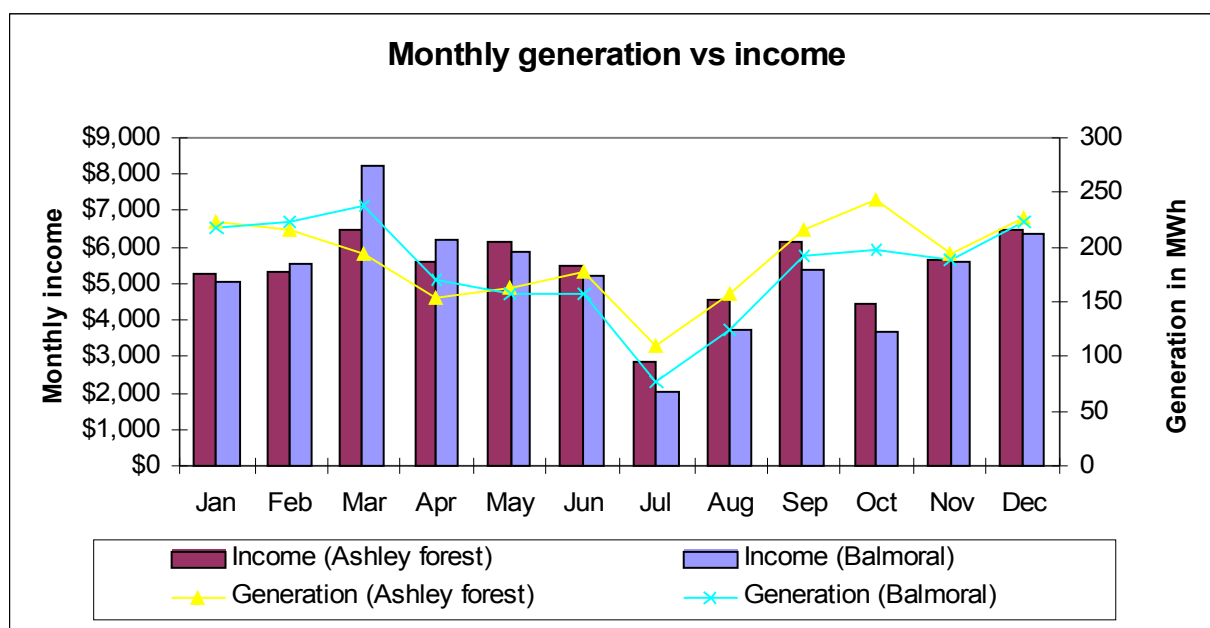


Figure 2. Graph of annual model output for the two NRFA weather stations

Finally, it is interesting to observe the considerable variation in monthly income. Expectations that lower generation in winter would be made up for by higher electricity prices proved not to be the case in 2000 with average electricity prices remaining reasonably consistent. It would seem that bursts of peak winter demand may send prices sky-high for very short periods of time but this has little effect on the average price. Perhaps this observation would not be true this year with low lake levels and looming power cuts.

	Ashley	Balmoral	Tararua
Annual Income	64439	62826	NA
Annual generation (MWh)	2270	2168	2850
Capacity factor	39%	37.5%	49%
Time below cut-in speed (5ms^{-1})	28%	33%	15% ¹
Time within operational wind speed	67%	59%	NA
Time above cut-out speed (25ms^{-1})	5%	8%	NA

Table 1. Annual statistics for study sites and Tararua comparison site

Total annual figures are presented in Table 1. A capacity factor of 39% is well above average for wind energy generators where 25-30% is considered reasonable (Krohn, 2001). The Tararua wind farm has an average annual generation of 2850 MWh per turbine, a full 25% higher than the Ashley site. In making this comparison though, it is worth considering that the Tararua site is regarded as one of the best in the country and the

¹ Reference from NZWEA (1999)

Ashley and Balmoral sites used in this report were not chosen by the NRFA for strong wind speeds. Also, although I have made the assumption in this report that wind speeds on Mt Grey will be the same as Ashley forest the exposed location may mean higher wind speeds.

3. ECONOMIC FEASIBILITY

In order to establish whether a wind-farm at Mt Grey is economically feasible we need to first decide what is meant by economic feasibility. The simple definition is that economically feasible means income exceeds expenditure. We can ask the question:

1. If I build a wind farm now will I make a profit by selling that electricity?

Electricity marketplace theory suggests that new generating capacity will usually be more expensive than current wholesale electricity prices. In a perfect, elastic market, when demand exceeds supply, prices will rise until it becomes profitable to build the most economical of the range of options for new generation capacity (WEMG, 1994). It is therefore possible to ask a second question:

2. When additional generation is next required will wind be the lowest cost option?

3.1. Methodology

To answer these questions we need to know the 'cost of energy' for the Mt Grey wind farm. Cost of energy calculations for the electricity market is usually quoted in cents per kWh. In order to calculate the cost of energy for Mt Grey we divide the expenditure by the amount of energy produced. This calculation is usually done on an annual basis though it may be calculated for different time bases (Walker, 1996).

Calculation of annual expenditure must include a portion of costs of expenditure over longer time periods. For example the large initial capital cost of a wind farm may be incurred over the entire lifetime of the farm. The standard method for converting the cost components of a project from varied time bases into an annual figure is the discounted cash flow analysis (Walker, 1996).

Discounted cash flow analysis

Capital expenditure uses an 'annuitised' value that depends on a financial discount rate and the project's financial lifetime (Walker, 1996). This leads to a simplified approach to calculating the average cost of energy:

$$\text{Cost of energy} = \frac{(\text{Annuitised capital cost} + \text{Average annual running costs})}{(\text{Average annual energy produced})}$$

In the United States there is a standard method for calculating cost of energy for new plants called the EPRI-TAG method. The EPRI-TAG method uses a standard financial discount rate of 10% and a project lifetime of 25 years to calculate the annuitised value. The annuitised value used in the EPRI-TAG method is .110 per dollar of capital. This standard annuitised value makes direct, cost of energy comparisons between different types of generation more valid. The project lifetime for a wind farm is usually 20 years, and in New Zealand's strong wind conditions it may be even lower. However the use of a 25 year figure may be balanced by a decrease in the financial discount rate as investor confidence in wind generation improves.

3.2. Cost of energy

The following table shows the figures used in the discounted cash flow analysis.

Five Vestas 600kW v47 turbines ²	\$3,900,000
Turbine installation and construction	\$200,000
Installation of a substation and grid connection ³	\$1,000,000
	\$5,100,000
Annual operation and maintenance costs	\$58,500
Annual annuitised cost of capital	\$559,470
Average energy produced based on Ashley forest output estimate	11,350,000 kWh

Table 2. Capital costs, running costs and energy output for the Mt Grey wind farm

These figures, inserted into the discounted cost analysis give the following result as our cost of energy.

$$\begin{aligned} \text{Cost of energy} &= \frac{(\$5,100,000 \times 1097 + \$58,500)}{(11,350,000)} \\ &= \$0.054/\text{kWh} \end{aligned}$$

3.3. Feasibility

The following table summarises the different costs of energy values calculated so far and introduces several more. It is important to note that there is no common, established method for comparing different energy projects in New Zealand so there may be inaccuracies in comparing cost of energy for the Mt Grey wind farm with cost of energy for new gas powerplants if those plants use different annuitised values.

	Cents/kWh
Estimated cost of energy for new gas power plants ⁴	4.3-4.5
Estimate cost of energy for Mt Grey wind farm	5.4
Average price for electricity on the spot market (2000)	2.95
Average price earned by the Ashley forest wind turbine (2000)	3.52
Average price earned by the Balmoral wind turbine (2000)	3.45
Baseline wholesale price ⁵ (2000)	3.9

Table 3. Summary of different cost of energy values

² Prices based on costs for the Tararua wind farm

³ Prices supplied by Orion

⁴ Reference from EECA (2001)

⁵ Reference from EECA (2001)

The baseline wholesale price takes into account the amount of electricity supplied as well as the price. It is higher than the average spot price because most energy supply occurs when demand, and therefore price, is high. Dispatchable energy sources such as gas generation and hydro can anticipate earning the baseline wholesale price. There is ready access to the spot market, which can accept non-firm energy, such as wind, with little difficulty (EECA, 2001). However the real barrier to entry in the spot market is that the non-firm nature of wind stops it from reliably obtaining top prices (EECA, 2001). In a worst-case scenario wind energy would earn less than the average market price because generation occurred when there was low demand hence low prices.

The actual results, shown in Table 3, are quite remarkable. These results show that the strong correlation between electricity generation and consumer demand we saw in the previous section translates into wind energy 'beating' the market average price by nearly 20 percent! In fact wind energy in North Canterbury earns just 10 percent less than the wholesale baseline price.

Nevertheless, now that we are able to answer the two questions posed at the beginning of this section we see that:

1. It is not profitable to build a wind farm on Mt Grey at this point in time. Based on these figures the cost of energy of wind needs to drop by 35 percent to breakeven.
2. It is not economically feasible to build a wind farm on Mt Grey to meet new supply requirements. Based on these figures the cost of energy of wind needs to drop by at least 17 percent to compete economically with gas generation.

Future feasibility

Although the Mt Grey wind farm is not economically feasible now it may become feasible in the future. The following variables may alter the economic analysis.

It is possible to consider large-scale hydro facilities as very large power plants with a limited fuel supply. There is the ability to supply large amounts of peak power, but it can't be done for very long. Adding wind generation allows the fuel to be conserved. Hydro stations can be upgraded with larger generators and higher flowrates and operate as "fast response" alternate generators to compensate when wind is unavailable. The economics change if you think about pairing wind energy with hydro generation because it becomes possible to earn the baseline wholesale price in the same way that gas generators can. Companies that own mostly hydro facilities such as Meridian and Trustpower (owners of the Tararua wind farm) are ideally placed to develop large-scale wind farms as additional 'fuel' for hydro lakes and such diversification may mitigate the effects of 'once a decade' bad hydro years.

Increased demand may see the 'real' electricity wholesale price (the price adjusted for inflation) increase. Increased demand in Canterbury, possibly as a result of higher irrigation demands because of more intensive farming and falling annual rainfalls would make electricity more locally expensive. Embedded generation in North Canterbury would have a natural cost advantage over grid-distributed generation elsewhere as savings on AC transmission losses are taken into account. Additional local power will also improve overall system reliability by adding power diversity (Anderson, 1996).

The capital cost per unit energy of wind has reduced to one quarter of costs twenty years ago (ECNZ, 1997). Abundant initiatives around the world are seeing larger turbines being commercialized. Simpler, more efficient generators, offer to increase turbine efficiency and reliability (Dettmer, 1998). The reduction in costs of power electronics and their integration into wind turbines may shortly make it possible to economically site wind farms up to 100 kilometers from the national grid via low cost HVDC connection (Dettmer, 1998). Additionally, local development initiatives from Windflow (Worrall, 2001) and Vortec (De

Vries, 2000) may see unit prices of turbines drop in price with the removal of transport costs and unfavorable exchange rates.

There may be a more favourable environment for financing wind energy developments in the future. Government policy initiatives could help to ensure the credibility of wind power developments. Changes in IRD regulations have resulted in shorter write-off times for wind turbines of just ten years. Lower discount rates for funding wind energy development could be part of initiatives to meet New Zealand's Kyoto protocol obligations. Even without government support it is possible that increased recognition of wind energy as a low risk investment may occur naturally.

There may be an increase in the cost of energy of alternate sources of new generation such as oil and gas. Natural gas supplies are unlikely to become a limiting factor in the next 15 years (EECA, 2001) but the need to meet Kyoto protocol obligations by offsetting emissions with forestry plantings may raise the cost of energy for fossil fuel generation.

4. ENVIRONMENTAL ASSESSMENT

Though the economic feasibility analysis is the main focus of this report, the environmental feasibility is just as important to wind site assessment. In order to assess the feasibility of Mt Grey I have studied the effects that arose in the resource consent hearing for the Tararua wind farm and considered how those effects apply for the Mt Grey site.

4.1. Consents and permission

A land-use consent is required from the Hurunui district council. A rural subdivision consent may also be required. The site is managed by the Department of Conservation and a twenty year crown lease would be needed.

4.2. Impact assessment

The existing microwave tower near Mt Grey may receive electromagnetic interference from wind turbines. The question of electromagnetic interference with an existing microwave tower arose in the resource consent hearing for the Tararua wind farm (Anderson, 1996). An expert witness testified that there were no radio-frequency emissions from wind turbines in the frequencies of concern for telecommunications companies.

It would be necessary to construct an extension to the access road of several hundred metres to allow access to Northern end of the ridgeline.

Building a high voltage cable to the nearest point of connection crossed will have little effect because it can follow established roads for the majority of the distance.

The direct ecological impact is likely to be minimal. The site is in tussock grassland surrounded by commercial pine forest on one side and mountain beech on the other. Studies have shown that wind turbines have little impact on local avian populations who get used to turbines. Night-feeding seabirds are particularly at risk as are large, migratory birds if a farm is placed in their flight path. Neither situation is relevant on the Mt Grey ridgeline. A tubular tower can discourage birds from perching near turbines. It is likely a wind farm on Mt Grey would use a trellis tower though because they present a lower wind profile and are more easily constructed in New Zealand. In this case perch guards can be used.

4.3. The 'natural character' debate

Whether wind generation on outstanding natural features is appropriate or "inappropriate" has not yet been debated under Section 6(a) of the Resource Management Act. It may be argued that wind turbines on Mt Grey impact the natural character of the area.

Mt Grey is used for recreational tramping purposes. There will be little direct impact to trampers as the area will not need to be closed to public access, the bottom of the turbine rotors will be more than 24 metres above the ground. There may be resistance from trampers who feel the turbines disrupt the area for tramping because of indirect effects.

The Mt Grey peak is prominently visible from most of North Canterbury but is a considerable distance from any habitation.

5. WIND RESOURCE ANALYSIS

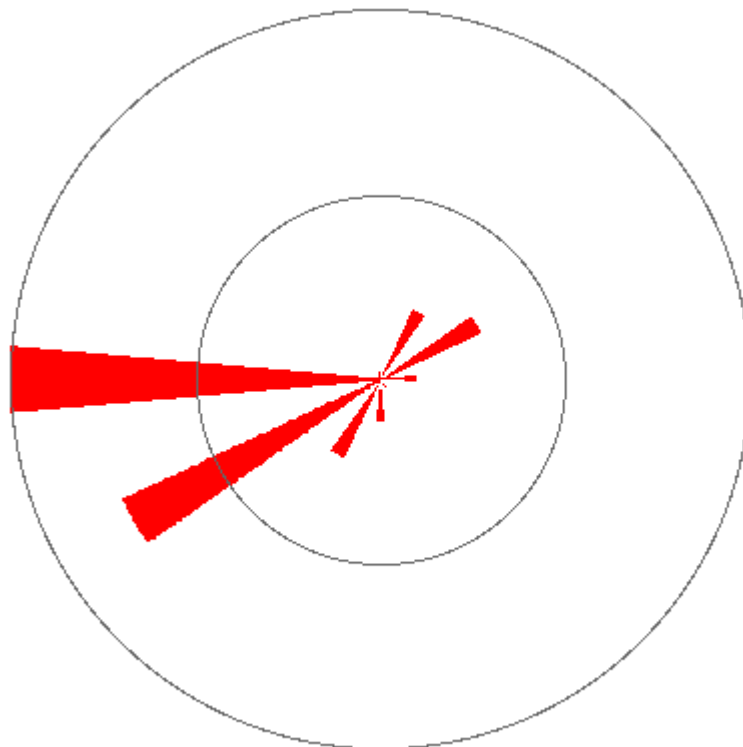
5.1. Wind direction analysis

In many cases the majority of the wind energy at a site will be supplied from one or two predominant directions. It is important to be aware of the predominant wind direction for a potential site as terrain features are more relevant in the predominant directions.

In order to find out what the predominant wind direction is for North Canterbury I plotted a 'wind rose' for the Ashley forest and Balmoral data (Krohn, 2001). A wind rose shows the nature of wind data by sector. The first sector corresponds to North, the fourth to east, seventh to south and tenth to west.

The energy of the wind is proportional to the cube of the wind speed (Redshaw & Dawber, 1996) so sectors with high mean wind speeds dominate the 'wind rose' energy plots even though wind from other sectors may be more frequent (Krohn, 2001).

It is evident from the data below that westerly winds dominate the wind energy profiles. The Ashley forest site is somewhat protected from Norwest winds by rough, forested terrain in that direction. It is likely the Mt Grey wind rose will more closely resemble Balmoral.



Wind Rose Plotter Programme Copyright © 1999 Søren Krohn

Figure 3. Ashley forest wind rose plot showing the distribution of wind energy per sector

Sector	1	2	3	4	5	6	7	8	9	10	11	12
Mean speed	4.42	6.91	8.27	7.73	5.46	5.8	8.04	10.23	12.71	14.34	4.9	3.98
Frequency	0.08	0.2	0.17	0.07	0.02	0.04	0.07	0.07	0.12	0.11	0.02	0.02

Table 4. Wind rose data for Ashley forest

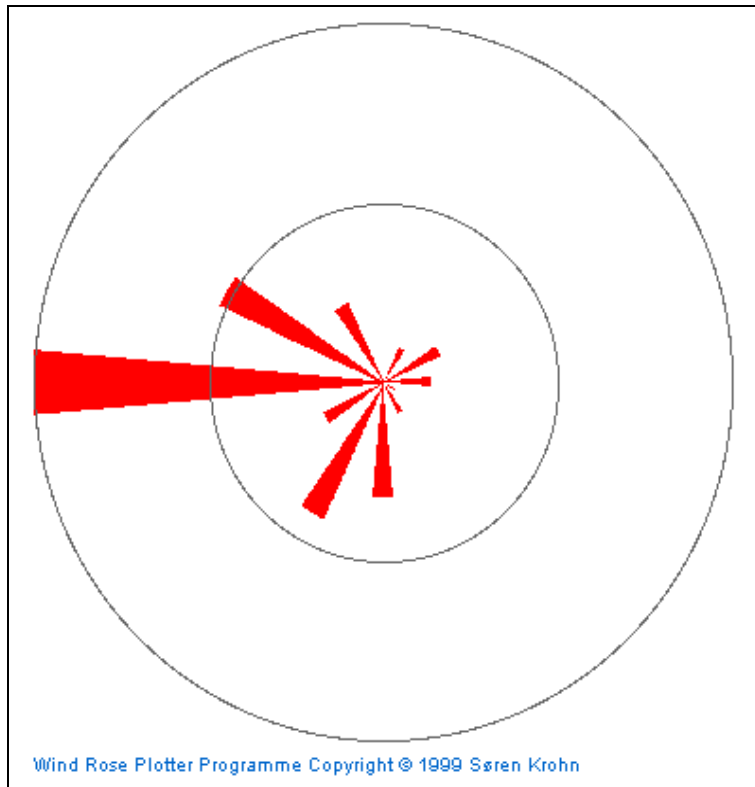


Figure 4. Balmoral wind rose plot showing the distribution of wind energy per sector

Sector	1	2	3	4	5	6	7	8	9	10	11	12
Mean speed	2.4	6.26	7.13	8.26	7.09	8.58	10.35	9.81	6.9	10.3	11.48	9.43
Frequency	0.11	0.09	0.1	0.05	0.02	0.03	0.06	0.09	0.12	0.19	0.07	0.06

Table 5. Wind rose data for Balmoral

6. CONCLUSIONS

The potential for wind energy generation in terms of GWh is clearly very high in New Zealand. The ability to match wind generation with hydro storage provides the potential to integrate much more wind into our national grid than other nations. The following conclusions can be directly drawn from this study:

- Direct hour-by-hour analysis of wind data and spot prices gives a much more accurate and wind favourable electricity price estimate than estimates based on annual averages.
- The mean wind speeds in North Canterbury are only infrequently above cutout speeds and do not significantly reduce the capacity factors of modern wind turbines. It has not been established whether or not instantaneous peak wind speeds are only infrequently above instantaneous cut-out speeds. Instantaneous cut-out speeds are usually 5ms^{-1} faster than average cut-out speeds.
- The cost of energy of the Mt Grey wind farm needs to decrease by 35 percent to meet the price of energy on the electricity spot market. If paired with a hydro facility for backup generation cost of energy would need to reduce by 28 percent.
- The cost of energy of the Mt Grey wind farm needs to decrease by 17 percent to be comparable with the cost of energy of new gas-fired generation.

7. FURTHER STUDY

There are several areas that require further study in order to refine the site assessment of Mt Grey including:

- Longer-term anemometer measurements are needed for the Mt Grey site itself to ensure the estimate based on Ashley forest data is accurate. Ideally 18-24 months of data are required at a site before there is enough information to reduce economic risk. Additional anemometer readings should be taken at a standard 10m height.
- Assess the suggestion that wind in Canterbury is too variable and/or strong and/or turbulent for wind energy to be viable here.
- Modelling of windflow around Mt Grey using a tool such as WaSP (Krohn, 2001) would provide more accurate location for turbine sites along the ridgeline.
- Surface roughness measurements, rather than estimates, are needed in order to ensure wind speed extrapolation to hub height is accurate. Roughness measurements are needed for each of the main directional segments. Alternately measuring wind speeds at different heights directly would establish the wind-height profile accurately.
- Multiple years and further sites around Canterbury need to be investigated to build up a better picture of long-term wind variability and answer some of the questions raised by the annual wind energy production analysis.
- It would be interesting to run the analysis with a range of different turbines to see whether the output can be further optimised and the economics improved. Perhaps the cost of energy for a 1.5 MW or 2 MW turbines would be lower. Perhaps a smaller rotor turbine such as the Vestas 600kW v39, which is rated up to 30ms^{-1} , may be better suited to Canterbury conditions.
- Capital costs in this report are quite rough and better more detailed estimates of actual capital costs would help to refine cost of energy estimates.

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Professor Chris Arnold from the Electrical Engineering department explained how the National grid operates.

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Dr Susan Krumdieck from the mechanical engineering department explained some wind phenomena and pointed out the existence of the vertical axis wind turbine.

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