Wind Energy Trading Benefits
Through Short Term Forecasting

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Summary

As the level of penetration of wind energy into individual grids has increased it has become necessary to make wind energy appear much more like conventional plant and hence to forecast the power production of wind farms. Historically there have been a number of studies investigating the possible methods of forecasting and the accuracy of their predictions. However, there have been a limited number of studies investigating the potential benefit of forecasting. This paper aims to address the issue by quantifying the potential financial benefits of forecasting for both individual, and portfolios of wind farms in the UK and Spain.

In the UK the market conditions are such that the benefit of forecasting wind farm production has been evaluated based on open market prices. For the Spanish case there is a more structured wind energy trading system whereby participants in the pool market are required to forecast. For both the UK and Spanish cases the trading calculations use data from online forecasting services combined with assumptions of the market conditions.

Based on the forecast data analysed and the assumptions used, there is the potential for increasing the value of wind energy in the UK and Spain by the amounts shown below

	UK £/MWh	Spain €/MWh
Single Wind Farm	+ 5	+ 7
Portfolio	+ 3	+ 3
Total	+ 8	+10

Key Words: Wind power prediction, forecasting, trading

1 Introduction

The focus within the wind energy industry over the past two decades considered primarily the industry's ability to estimate long term energy production for a wind farm. Usually this is the most important task since, until recently, all the Power Purchase Agreements, in Europe at least, are "Take or Pay", meaning that the utility or other customer is obliged to buy all the energy produced by the wind farm at a set price no matter at what time of day or year it is produced. As such, the application of energy prediction figures has usually been limited to use within long term economic forecasts and sensitivity analysis for investment purposes. This is a luxurious position which is unlikely to persist, primarily because the increasing penetration of wind generation, in terms of the overall energy mix, will cause fluctuations in energy output to be more visible on the electrical system. The Independent System Operators (ISO's) working to balance supply and demand on a regional or national grid system will need to predict and manage this variability to avoid balancing problems.

As the level of penetration of wind energy into individual grids has increased it has become necessary to make wind farms appear much more like conventional plant and hence to forecast, at short to medium time scales of one hour to a few days, how much energy will be produced. Cases where the penetration of wind energy is such that forecasting is required are: Denmark, Germany, Spain, California, Ireland (for wind farms greater than 30 MW) and the NEMMCO system in Australia. In other locations it is a commercial choice as to whether wind energy forecasts are utilised or not, e.g. the UK, the USA, and Ireland. This paper is focused on evaluating the benefits of utilising short term forecasts for wind energy trading. These benefits have been evaluated for the UK and Spain based on results from online GH Forecaster services, the forecasting service provided by Garrad Hassan and Partners Ltd (GH).

GH have been predicting the long term energy production of wind farms on a commercial basis for more than 15 years, and internationally GH have analysed more than 40,000 MW of projects. A more recent but natural extension of GH's long term energy production prediction services, has been to develop a method for the forecasting of the future energy production of wind farms over a time frame of a few hours to a few days. This development culminated in the launch of the GH Forecaster service, now operational for over 20 sites in 5 countries around the world.

This paper presents a brief description of the forecasting method and the trading analysis conducted, the results, and a discussion on their interpretation and applicability. A number of studies have investigated potential forecasting solutions; however, there are a limited number of papers quantifying the benefit of forecasting. This paper aims to address the issue by evaluating the potential financial benefits of forecasting for both an individual, and portfolio of wind farms in the UK and Spain.

2 Method

2.1 Modelling method

The GH forecasting modelling method incorporates input data from a Numerical Weather Prediction (NWP) source of appropriate resolution, and from on site data. An overview of the process is shown in Figure 1 below.

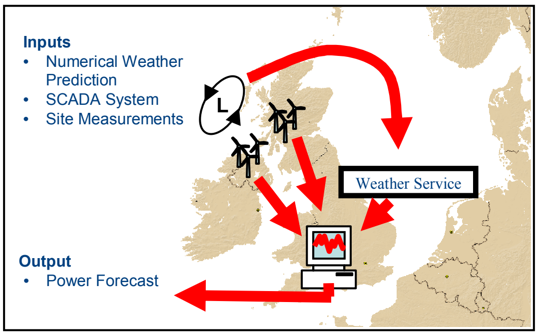

Figure 1 Method overview

The physical aspect of the modelling methodology is primarily provided by the NWP input. This input is enhanced through the application of multi-parameter statistical regression routines. Further details of the modelling method used can be found in [1] and [2]

The creation of power output forecasts within GH Forecaster is a two-stage process. First, through the adaptation of the NWP input, there is the creation of site-specific meteorological forecasts. These meteorological forecasts are then transformed, via site-specific power models, to power output forecasts. To enable the models to be both auto-regressive and adaptive, feedback data from the site is also required. This is shown schematically in Figure 2 below.

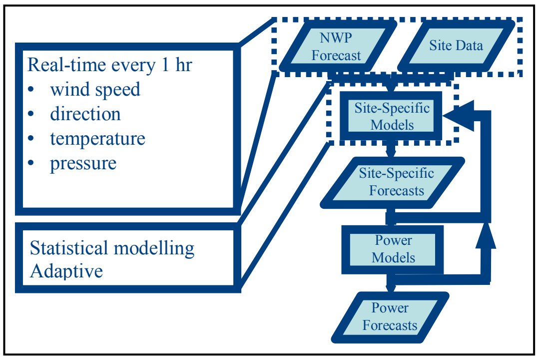

Figure 2 Forecasting process

2.2 Trading evaluation

The wind energy trading evaluation was based on the UK and Spanish markets; these operate based on different regulations and consequently the analysis has been separated out. However, both markets follow the same basic principle that the overall income from selling wind energy is higher the more accurate the forecast.

Firstly dealing with the UK market. Although GH is not an energy trader and does not suppose to understand all the intricacies of energy trading, through discussions with clients it is understood that assumptions made in the evaluation of trading wind energy are reasonable for the purposes of the analysis. Key assumptions are:

- Trading calculations are based on day-ahead predictions of wind farm production.
- Trade price has been taken as average of sell and buy prices, GH acknowledge that when trading a day in advance it is likely that the trade price would not be the instantaneous average but some longer term average price that would smooth out the peaks and troughs of the fluctuating prices.
- The entire forecast is sold at the trade price.
- If excess energy is produced then this is sold at the "sell price".
- Any shortfall is bought at the "buy price".
- Prices were obtained from the Elexon website, "Best View Prices": http://www.elexon.co.uk/marketdata/PricingData/default.aspx as shown in Figure 3 below.

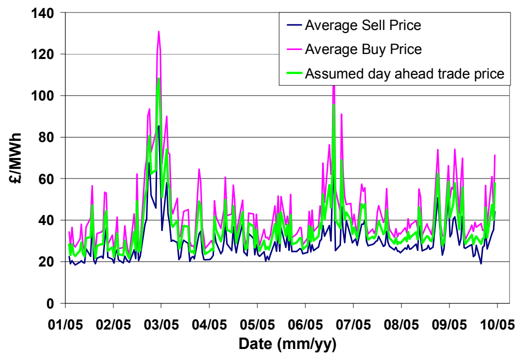

Figure 3 UK energy prices

For the Spanish market the wind energy was assumed to be traded on the pool market, participation in this market requires the producer to forecast production, with penalties applied if actual production deviates from the forecast. The evaluation included daily and intra-daily predictions, further definition of the timing of the daily and intra-daily predictions can be found in Section 3 below. The following market assumptions were made:

- Average pool price = €56 per MWh (based on average OMEL prices for 2005)
- Deviation penalty = 27% of pool price
- Reference Tariff (TMR) = €76.6 per MWh
- Power guarantee = €4.8 per MWh
- Premium = 40% TMR
- Incentive = 10% TMR
- Reactive power complement = 4% TMR

Giving a Market Tariff of:
= €102.2 per MWh – penalty

The market penalty is calculated as:

$$(|\text{Forecast Energy - Actual Energy}|) \times 27\% \text{ of } €56 / MWh$$

The alternative option for wind energy producers is to sell the energy using the Regulated Tariff, where forecasting is currently not required.

Regulated Tariff = 90% TMR + reactive power complement = €72.0 per MWh

It is apparent that based on the above assumptions the minimum that a producer would be paid in the pool market would be 102.2 – 27% of 56 = €87.08/MWh, considerably more than the regulated tariff. Therefore, if the market price remains close to or above €56 per MWh, then selling wind energy on the Spanish pool market will be the favourable option.

3 Results

The results presented are based on online predictions for wind farms in the UK and Spain. The trading calculations were conducted using input from the online predictions and using the assumptions defined in Section 2.2 above. Figure 4 below shows an example of a typical energy forecast and the corresponding wind farm production over a period of 25 days. The chart shows hourly data for forecasts produced 24 hours in advance. It is clear that although the wind energy is variable, it is still predictable.

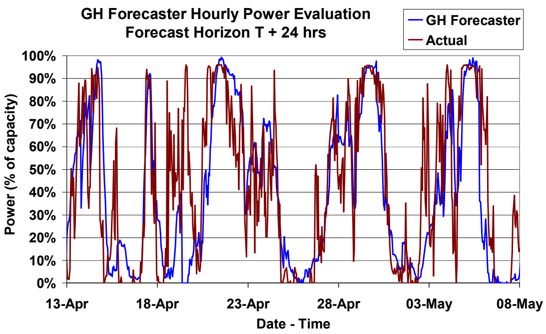

Figure 4 Time history of GH Forecaster predictions 24 hours in advance and actual wind farm production.

3.1 UK, Single Wind Farm Analysis

As stated in the assumptions for the UK analysis, the data for the UK energy prices was obtained from the Elexon website. Figure 3 in the previous section shows the data obtained from the site and the assumed day-ahead trade price of half way between the buy and sell prices.

The chart of UK energy prices clearly shows that over the period between January and October 2005 the energy price fluctuates considerably during certain periods. To minimise the effect of the fluctuating prices causing a bias in the trading calculations an average of the buy and sell prices was used as the trade price, thereby forcing the penalty of over or under predicting to be equal.

Using the above energy prices and online forecasts for a single wind farm in the UK, gave the result shown in Figure 5. The chart shows the average energy price that wind farm production could be traded at using day-ahead predictions, depending on the weighting given to the forecast. For example when the bid factor is zero the energy is all "spilt" onto the system at the sell price, the average of which during the 10 month analysis period was approximately £28.5/MWh. As weight is given to the forecast for the energy trade, so the average revenue increases to an optimum value around a bid factor of 1.

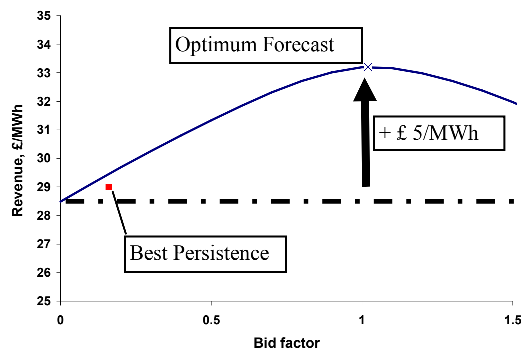

Figure 5 UK wind farm revenue

As discussed earlier the trade price assumptions forced the penalty structure for over or under forecasting to be equal; therefore an optimum bid factor of 1 shows that, on average, for the period analysed there was no bias to the forecasts.

The significant point to note from Figure 5 is that the potential increased revenue through utilising a sophisticated forecasting system for day-ahead trading compared to simply spilling energy, is of the order of £5/MWh. Taking the case of a 50MW wind farm operating at a capacity factor of 30%, forecasting could enable an increase in annual revenue of almost £660,000 when compared to spilling energy onto the grid.

An alternative simple method of forecasting is to use persistence based forecasts, effectively assuming that what happens now will persist into the future. The red square on Figure 5 shows the optimum revenue from a persistence forecast, and as would be expected for day-ahead predictions the average revenue using persistence forecasts is only slightly above spilling energy onto the grid.

3.2 UK, Portfolio Analysis

The same analysis that was conducted for a single wind farm was performed on a portfolio of wind farms. Due to limitations with concurrent quality data this analysis could only be based on a period from October 2005 to January 2006. As can be seen from Figure 6 below the energy prices during this period were much higher than earlier in the year and included significant fluctuation. Although this resulted in different absolute portfolio results compared with the earlier example, the comparison between the portfolio calculations compared to the individual wind farm results for the same time period are still valid.

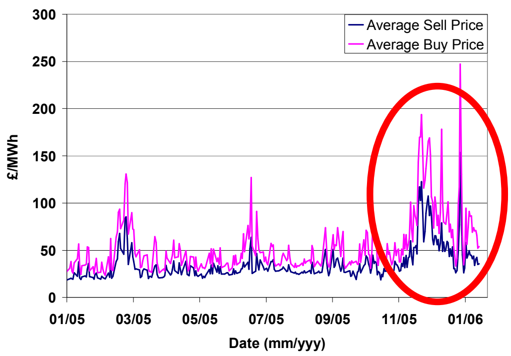

Figure 6 UK energy prices

The benefit of summing the power from a portfolio of wind farms is shown by the Mean Absolute Error (MAE) calculations in Figure 7.

$$MAE = \frac{\frac{\sum_{1}^{N}\left(\left|Power_{GHForecaster} - Power_{Actual}\right|\right)}{N}}{Rated\ Power}$$

Where N is the number of predictions

This chart shows that for the limited period studied, during which time it was not possible to employ the optimal modelling techniques due to poor data feedback, the MAE of the energy forecasts for the portfolio is approximately 5 % lower than for the weighted average of the individual wind farm results. The portfolio forecast is the prediction of the sum of the production from the separate wind farms. The reduction in error is due to synoptic weather conditions effecting different sites at different times, reduced localised topographic effects and reduced overall random errors. These together are often referred to as the portfolio effect.

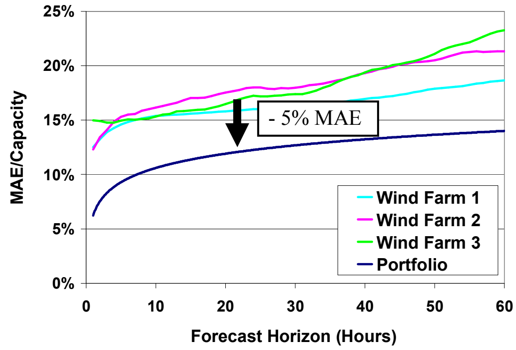

Figure 7 Mean Absolute Error for individual wind farm predictions and the portfolio prediction

Consequently the reduced errors in the portfolio prediction result in increased revenue, as shown in Figure 8 below. The increased revenue is taken as the difference between the weighted average of the peak revenue from the individual wind farms compared to the peak revenue from the portfolio. This calculation results in a potential increased revenue due to the portfolio effect of £3/MWh. The reason that the optimum bid factors for this chart are not 1 is because the data used for analysis had large fluctuations in energy prices thereby causing a greater weighting on the periods with very high price. If during one of these periods the predictions were high or low this resulted in biased energy trading calculations.

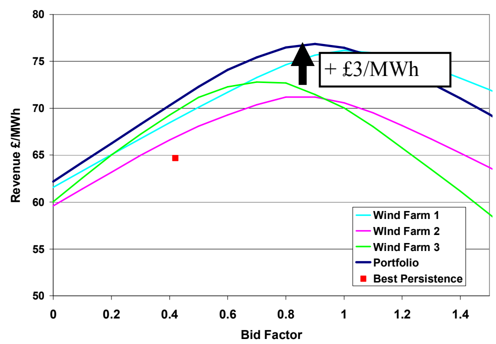

Figure 8 UK portfolio revenue

Care should be taken not to compare Figure 8 directly with Figure 5 as they are for different periods, instead the portfolio assessment is focused on the relative comparison of the results in Figure 8, which clearly shows the benefit of forecasting for, or trading energy from, a portfolio of wind farms.

The three wind farms used for the UK portfolio analysis have a maximum separation of 450 km and a minimum of 180 km, the ratio of wind farm capacities are 2.5 : 1 : 2.2. It is speculated that the portfolio benefit would diminish as the wind farm separation decreased, and the reduction in forecast accuracy, and therefore increased revenues, would asymptote as the number of wind farms included in the portfolio increased. However, the investigation of these hypotheses has not been included within the scope of this study.

For the portfolio analysis, the comparison with persistence forecasting still shows a significant improvement. However, the optimum bid factor for persistence is greater than for the single wind farm case, indicating that the portfolio effect also reduces the errors of this simplified forecasting method.

3.3 Spain, Single Wind Farm Analysis

As stated earlier the analysis for the Spanish case was based on daily and intra-daily predictions. Daily forecasts are made at 10:00 and contain predictions of the hourly wind farm production for the following day, 01:00 to 00:00. Intra-daily predictions are separated in 6 sessions where there is the opportunity to update the daily prediction. Figure 9 below illustrates the potential revenue from a single Spanish wind farm calculated using online forecasts and using the assumptions stated in Section 2.2 earlier, note the y-axis starts at the baseline level of €87/MWh assuming no forecasts are used.

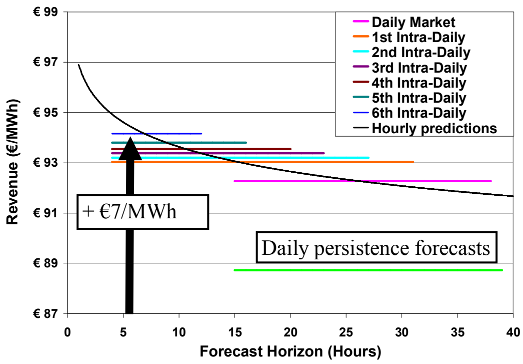

Figure 9 Spanish wind farm revenue

The chart shows the average net price that the wind energy might be sold at if a new forecast were to be issued every hour containing hourly predictions out to 40 hours in the future. However, in reality it is only the daily and intra-daily forecasts that are used for trading, so these forecasts, their horizons and corresponding average revenue levels have been illustrated on Figure 9. All calculations assume a constant pool market price of €56/MWh for the daily and intra-daily predictions.

As one would be expect, the potential revenue through utilisation of the intra-daily predictions for shorter time horizons yields higher average energy prices. For the single wind farm case, good quality, regular feedback of wind farm measurements were available, which enhanced the capability to achieve better accuracy forecasts, and therefore higher revenues from the intra-daily predictions.

In addition to the potential increased revenue for the intra-daily predictions the two key points to note are: firstly the fact that participating in the pool market, through the utilisation of sophisticated forecasts can yield a return of approximately €92.5/MWh, which is considerably greater than the €72.0/MWh from the regulated tariff; and secondly that, when compared to the simplified persistence forecasting method for the daily predictions, the return using the GH Forecaster system is shown to be greater than €3/MWh higher.

If the use of forecasts for the intra-daily sessions is considered, a price of €94/MWh is achievable; when compared to the case of providing no forecasts, where a value of €87/MWh would be the baseline (see the Spanish assumptions in Ssection 2.2), this shows the potential of sophisticated forecasting to increase the value of the wind energy by €7/MWh.

3.4 Spain, Portfolio Analysis

The same analysis that was conducted for a single wind farm was performed on a portfolio of wind farms in Spain. The three wind farms used for the Spanish portfolio have a maximum separation of 600 km and a minimum of 280 km, the ratio of wind farm capacities are 1.5 : 3.3 : 1.

Unfortunately, due to the unavailability of live feedback for the sites assessed for the portfolio, less sophisticated models were used. However, the relative comparison between the results for individual wind farms and the portfolio is still valid. Figure 10 below, shows that when forecasting the sum of the production from the wind farms, the accuracy is approximately 5% better than for the weighted average accuracy of the individual predictions. This portfolio effect is very similar to that observed for the UK case and confirms that this effect is likely to be applicable under a variety of conditions.

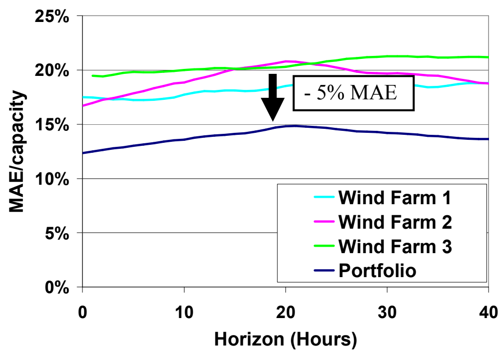

Figure 10 Mean Absolute Error for individual wind farm predictions and the portfolio prediction

As expected the lower portfolio errors result in higher portfolio revenue when compared to the average individual values, as illustrated in Figure 11 below.

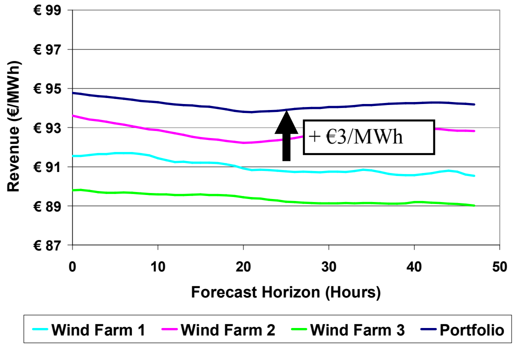

Figure 11 Spanish portfolio revenue

The increased revenue is taken as the difference between the weighted average of the revenue from the individual wind farms compared to the revenue from the portfolio. This calculation results in a potential increased revenue due to the portfolio effect of €3/MWh

3.5 Forecast Certainty

A relatively recent area of investigation for GH is the area of short term forecast certainty. Current GH methods involve adaptive models not only "learning" how the weather patterns behave at a site to enhance the NWP input but also "learning" the probability of occurrence of weather events and therefore power levels. Essentially using historical data for a site the probability of a given power level occurring can be calculated based on appropriate weather and power model parameters. This process has been used to generate the results shown in Figure 12 below.

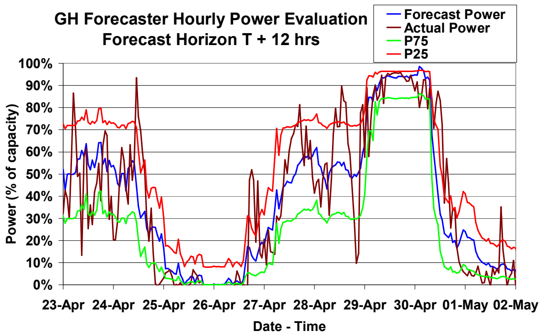

Figure 12 Forecast certainty time history

The chart shows a time history of forecast power and actual production combined with forecasts of P75 and P25 values. A P75 forecast is a forecast of the power level that is likely to be exceeded 75% of the time, similarly a P25 value should be exceeded 25% of the time. This additional information to the forecast itself should enable the better utilisation of the forecast.

Although for the case studies in the UK and Spain the penalties associated with under or over predicting were assumed to be the same, it is likely that in reality this will not always be the case and forecast certainty will aid in the process of minimising penalties. Investigation of the single wind farm case in Spain showed that on average there was no bias to the forecasts; however, more detailed investigation using forecast certainty showed that the overall even distribution of errors consisted of identifiable cases where there was an uneven error distribution.

Using the forecast certainty method described above applied to the single Spanish wind farm case enabled the generation of the results shown in Figure 13 below. As there is no bias in the penalty scheme for Spain, the increased revenue in the predictions was achieved through minimising forecast error as opposed to minimising the penalty. However, the identification and eventual reduction of error was made possible through forecast certainty analysis.

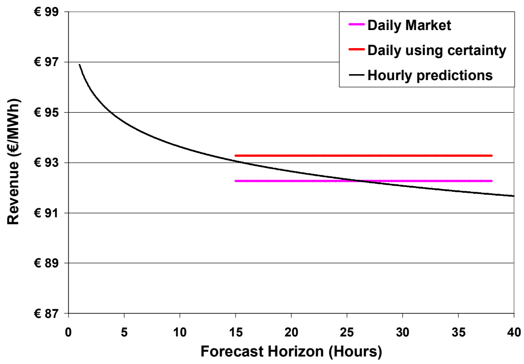

Figure 13 Increased Spanish wind farm revenue

GH acknowledges that further work is necessary to improve the understanding of forecast certainty and its possible application. GH are currently investigating working with forecast certainty from NWP suppliers as well as historical data to better evaluate uncertainty at the source, as opposed to only post processing data. One area of investigation is the utilisation of Ensemble NWP forecasts whereby the initial conditions, and/or the model assumptions of the NWP models are perturbed and multiple runs are conducted using the varying model conditions.

4 Conclusions

This paper shows that the technology is in place for short term forecasting to be exploited in the wind industry. There are potentially real financial benefits to be made in the immediate term through utilising forecasting of short term wind farm production.

Based on the forecast data analysed and the assumptions used, there is the potential for increasing the value of wind energy in the UK and Spain by the amounts shown in Table 1 below

	UK £/MWh	Spain €/MWh
Single Wind Farm	+ 5	+ 7
Portfolio	+ 3	+ 3
Total	+ 8	+10

Table 1

This immediate term benefit to organisations trading in wind energy should lead to longer term benefits to the wind industry as the increased application of forecasting enables greater penetration of wind power, and potential long term benefits to the energy consumer due to market forces driving energy costs down.

5 References

1. J. R. Parkes "Forecasting Short Term Wind Farm Production in Complex Terrain" EWEC 2004.
2. G. Gow. "Forecasting Short Term Wind Farm Production". DTI contract no. W/45/00572. 2003