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Wind Energy in Ireland - An Analysis of Percentage Error in Forecasting

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Declaration of authorship

I, Michael McDonald (H 00020971)

confirm that the dissertation entitled -

Wind Energy in Ireland - An Analysis of Percentage Error in Forecasting

is part of my assessment for module *Masters Dissertation*

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Abstract—

This research aimed to examine the percentage error in forecasting of wind energy using datasets from a small wind farm in Ireland. Furthermore, the study aimed to compare this calculated data to the national forecasting percentage errors. Internationally, the electrical sector and society are undergoing a revolution in terms of 'green economy'. This paradigm shift towards renewable energy technologies is recognised as a priority, with diminution of finite fossil fuels at its core. Renewable energy as a sector has provided significant financial stimulation to global economies in recent years. Moreover, wind energy has provided significant amounts of clean electricity throughout the world. However, due to its very nature, wind energy presents uncertainties which lead to errors in forecasting, which this study aimed to analyse.

It is believed that accurate wind energy forecasting will allow establishment of an appropriate generation mix in future electrical networks. Thus, forecasting and percentage error is essential to wind energy integration, especially as installed capacity is estimated to increase substantially in the coming years. Using datasets based on various time series, this research collated, calculated and analysed the percentage error between predicted and actual wind energy output from a small wind farm (micro level) and at a national level (macro level). The findings of the research were that at the micro level there was a percentage error of -0.36% and at the macro level a percentage error of 5.7% over a twelve month period.

The data in this study gives great insight into wind energy forecasting and the research discusses the effects of percentage errors in the renewable energy sector as wind capacity increases.

***Key words*:** Wind Energy, Percentage Error, Forecasting

1. Introduction:

"If we don't change direction soon, we'll end up where we're heading"

(IEA 2011)

The International Energy Agency's (IEA) *Wind Energy Roadmap 2013*, contends that if decisive action is not taken, energy related CO_2 emissions will more than double by 2050. Thermal electricity generation is a known large contributor to these emissions. Thus, this method of generation and society's current trends in relation to energy supply and usage are unsustainable - economically, environmentally and socially (IEA 2013 A). The electricity sector and society as a whole are undergoing a revolution in terms of a green economy. This paradigm shift towards renewable energy technologies is recognised internationally as a priority, with reduction of finite fossil fuels at its core. However, large scale integration of renewable energy into existing networks presents challenges, such as, co-ordinating fluctuations and intermittent generation (Lund 2010).

Wind energy is regarded as a mature technology and since 2008 wind energy deployment has more than doubled globally to 300 Giggawatts (GW). Moreover, wind energy now provides 2.5% of global electricity demand (IEA 2013 A). At a European level, 2013 witnessed the installation of 11 GW of wind energy. This was a decrease of 8% compared to the previous year, and provides Europe with an installed capacity of 117,289 Meggawatts (MW). In comparison, Ireland's national installed wind capacity in 2013 was 2,037 MW (EWEA 2014).

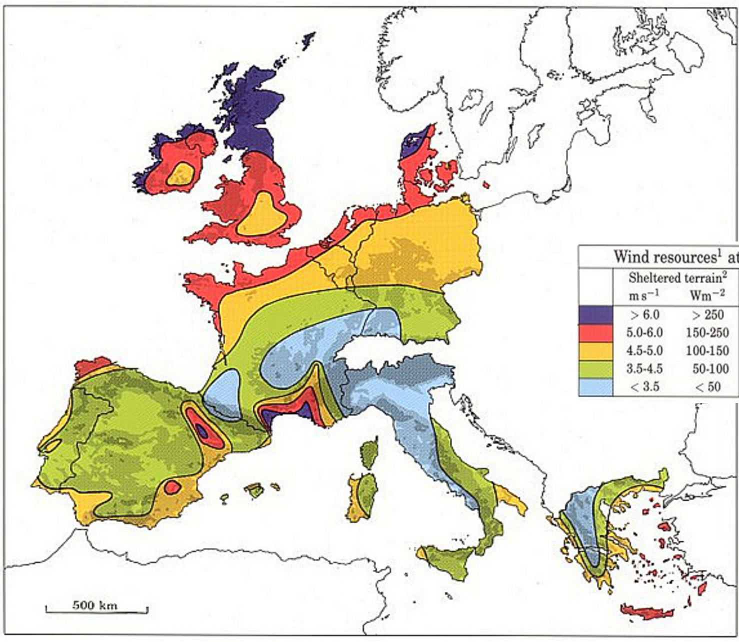
1.1 Background:

In Ireland, during the period 1990 - 2007, demand for energy grew by 84% (DCENR 2008). This clearly indicates that there has been a progressive increase of energy usage over the last two decades. Moreover, the International Energy Agency (IEA) predicts that there will be further increases worldwide in the coming years, quoted as 45% by 2030 and doubled between now and 2050. The Irish government along with all Member States of the European Union (EU) set out a target to counteract the increasing trend by reducing energy demand by 20% and installing 40% renewables by the year 2020. This initiative is known as the '20-20-20' scheme (Directive 2009/28/EC). Encouragingly, the Irish Government took this further by setting an even higher energy reduction target of 33% throughout the public sector (DCENR

2007). However, in the first quarter of 2014 these ambitious targets were removed from individual Member States, with the intent to provide greater flexibility. This amendment was introduced as a result of the economic and financial crisis which affected Member States' ability to invest in renewable technologies (EC 2014).

Looking now to Ireland specifically, Ireland's dependency on imported fossil fuels is amplified due to the lack of indigenous fuel reserves. The largest national reserve to date in Ireland is Kinsale, off the coast of Cork (Southern Ireland), and more recently The Corrib, off the coast of Mayo (Western Ireland). Furthermore, Ireland's geographical location on the periphery of Europe further contributes to its vulnerability to supply disruption and economic volatility. Moreover, this presents a direct threat to national security of energy supply.

Focusing on wind energy in Ireland, Ireland has one of the greatest wind energy resource potential in Europe, as demonstrated in Figure 1. However, to date the full potential of this natural resource has not been fully embraced in terms of targets and output. According to Eirgrid (2014), a mere 18% of Ireland's electricity demand is provided by wind energy, which stands in stark contrast to the vast energy that could be harnessed based on the Wind Atlas study below. Thus, referring to the installed wind energy capacity in Ireland and the ability to meet EU targets (pre amendment document) Ireland is falling disappointingly short.



Wind resources[1] at 50 metres above ground level for five different topographic conditions

	Sheltered terrain[2]		Open plain[3]		At a sea coast[4]		Open sea[5]		Hills and ridges[6]	
	$m s^{-1}$	Wm^{-2}	$m s^{-1}$	Wm^{-2}	$m s^{-1}$	Wm^{-2}	$m s^{-1}$	Wm^{-2}	$m s^{-1}$	Wm^{-2}
	> 6.0	> 250	> 7.5	> 500	> 8.5	> 700	> 9.0	> 800	> 11.5	> 1800
	5.0-6.0	150-250	6.5-7.5	300-500	7.0-8.5	400-700	8.0-9.0	600-800	10.0-11.5	1200-1800
	4.5-5.0	100-150	5.5-6.5	200-300	6.0-7.0	250-400	7.0-8.0	400-600	8.5-10.0	700-1200
	3.5-4.5	50-100	4.5-5.5	100-200	5.0-6.0	150-250	5.5-7.0	200-400	7.0- 8.5	400- 700
	< 3.5	< 50	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 7.0	< 400

Figure 1

Europe's Wind Atlas

Source: http://www.windatlas.dk/europe/landmap.html

Examining in further detail the 18% installed wind capacity in Ireland, Figure 2 demonstrates the breakdown of such capacity across the 26 counties of the Republic of Ireland. This breakdown was collated and graphed using data published by the Irish Wind Energy Association (IWEA). The counties with the highest wind capacity in Ireland are the Atlantic coastal counties of Cork, Donegal and Kerry respectively. A number of midland counties such as Tipperary and Cavan also offer substantial wind capacity. The lowest yielding county for wind energy in Ireland is the capital city of Dublin on the east coast of Ireland.

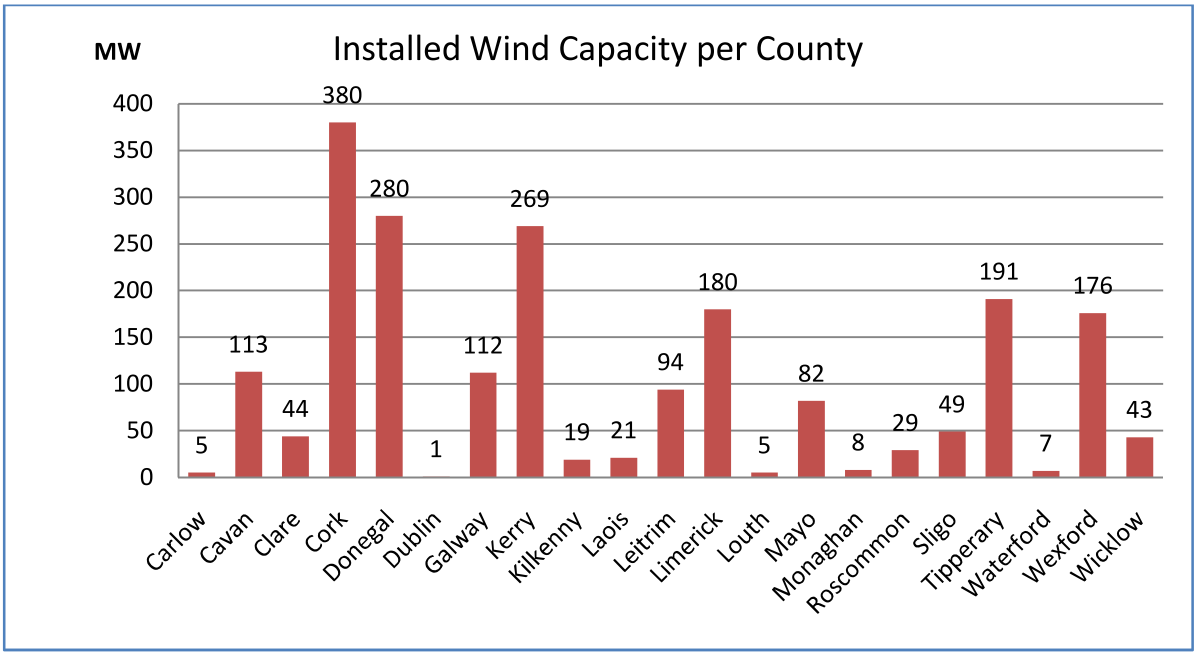


Figure 2

Ireland's Installed Wind Energy Capacity per County

Interpreted from the Irish Wind Energy Association (IWEA)

Source: http://www.iwea.com/windfarmsinireland

Having examined Ireland's potential wind capacity, followed by the installed wind capacity across the nation, it is now imperative to investigate the actual wind generation in Ireland and how it compares to the vast national demand for energy previously stated. Figure 3 below illustrates Ireland's wind energy generation over a twelve month period (February 2013 - January 2014) and the difference between the level of generation versus the level of national demand. This data was gathered from a number of sources within Eirgrid's published data and was collated and illustrated graphically for the purpose of this research background information.

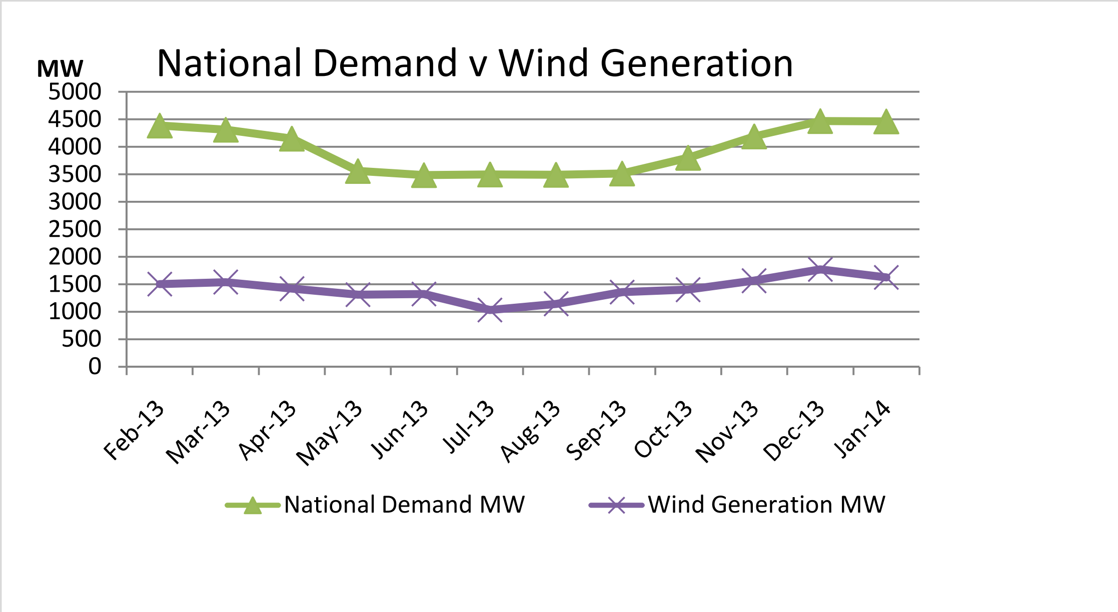


Figure 3

Interpreted from Eirgrid's data

Source: http://www.eirgrid.com/operations/systemperformancedata/systemdemand/

This graph clearly shows that there is substantial deficit between the national demand for electricity and the actual level of wind energy generation. It is evident that if Ireland is to meet the target of 40% renewable electricity, it is estimated that the amount of installed wind capacity will need to be in the region of between 3,500 MW and 4,000 MW by 2020. This means that Ireland will have to install 250 MW of wind energy each year to 2020. Encouragingly, in 2012 instantaneous wind penetration exceeded 40% of the system demand for 46 days throughout the year (Eirgrid 2014).

1.1.1 Financial Aspect of Renewable Energy:

Renewable energy, as a sector, has provided significant financial stimulation to global economies in recent years. In fact, global investment in renewable energy in 2012 was $244 USD billion, which was down from $279 USD billion in 2011 (REN 21 2013). The largest uptake of wind technology is by the United States (U.S.) and China, with the latter installing 13 GW (27% of the global installed capacity) in 2012. Ireland's protracted implementation of alternative energy resources, through regressive policy and lack of investment, leaves the 40% target seeming unattainable at this stage. Regardless of targets being achieved or not, the wind energy sector is rapidly increasing. Moreover, wind will likely provide a larger percentage of the electricity generation mix.

Historically, the beginning of large scale turbines was the 1.25 MW turbine installed in the U.S. in 1953 (Letcher 2008). Since 1953, there has been major turbine product intensification with the output capacity of the turbines being manufactured witnessing steady growth over the last decade, as well as increase of the actual scale of wind farms.

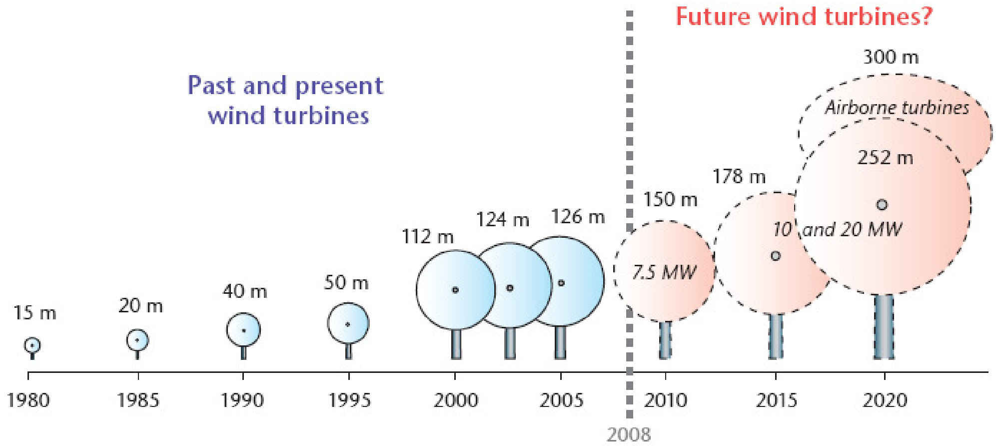


Figure 4

Wind Turbines of the Future

EWEA 2009

Figure 4 above clearly demonstrates this product development in relation to the wind turbines, showing huge increase in size and output capacity. The development of product and wind farm size has a direct correlation to the increased capital investment which is now required to develop such projects. Below the IEA (2010) outline the typical cost associated with wind farm development, with the main outlining cost being that of the wind turbines themselves.

Typical Wind Farm Costs:

- 65 % = Turbine
- 12 % = Grid connection
- 8 % = Onsite electrical
- 8 % = Civil engineering
- 4 % = Development
- 3 % = Legal / Financial

(IEA 2010)

With a better understanding of the financial aspects of the wind farm industry it leads to the central topic of wind energy forecasting. Findings published by Hodge and Milligan (2011) suggest that more accurate wind energy forecasts and reduced errors, can lead to economic efficiency as fewer generation reserves needed to be kept. Currently, wind energy supplying 10% and 20% of electricity demand requires 3 - 6% and 4 - 8% additional reserve respectfully (Boyle 2009). The result of these important findings lead to the subject of this research, that forecasting and the associated percentage error in relation to actual and predicted wind energy output has arrived centre stage in this high stakes market.

1.1.2 Wind Energy Conversion:

Wind energy, similar to wave, requires the generating plant to withstand extreme conditions without being destroyed (Boyle 2009). Wind turbines extract kinetic energy from moving air, converting it into mechanical energy via the turbine rotor and then into electrical energy through the generator. The two defining aspects of a wind turbines performance are the blade sweep area and the associated wind speed for the given location. Thus, small variations in wind speed tend to have a significant impact on wind turbines output capacity. Wind turbines are currently designed to withstand wind speeds of 25 metres per second (m/s) (Boyle 2009). Finally, Betz's law states that no turbine, due to aerodynamic conversion losses, can capture more than 59.25 % of the kinetic in the wind.

1.1.3 Wind Energy Forecasting:

Wind energy has already provided significant amounts of sustainable, pollution free electricity throughout the world (Letcher 2008). However, due to its very nature, it presents uncertainties which alongside Numerical Weather Predictions (NWP) models lead to errors in forecasting. There are many different methods used to forecast wind energy, but all are based on synergistic blend of statistical and physical methods which involve components, such as, wind / weather data, power curve, downscaling and Computer Fluid Dynamics (CFD) (Kariniotakis et. al. 2003). Typically, forecasts for wind energy are given for multiple forecast horizons, or the time ahead for real time for which the forecast is made. In fact, forecasts are computationally and financially expensive to produce. Thus, simulated or synthetic forecasts tend to be incorporated into wind integration studies (Bielecki 2010).

1.2 Aims and Objectives:

Today, electrical networks globally are witnessing large scale integration of wind energy (Letcher 2008). Ireland is unique, in that it has abundant wind resources, has an autonomous grid and is interconnected to Europe. This study intends to evaluate this very resource in Ireland. The overarching aims and objectives of this study were to examine the percentage error between actual and predicted wind energy output. It aims to analyse the errors which occur in wind energy forecasting and to evaluate the performance of modern forecasting. This research will examine datasets and investigate the relationship between forecasting at micro and macro levels and the associated challenges. In order to evaluate the volatility of this natural resource, the research was categorised into two sections, the present and potential future scenarios.

1.3 Outline:

The purpose of the outline is to give a brief overview of the sections to follow. Firstly, the subsequent section describes in detail the methodology which was meticulously followed for the purpose of this study, describing clearly the process used to analyse the datasets for all scenarios. The following sections present and discuss the main findings of the research.

2. Research Methodology:

Williams (2007) contends that research methodology is that of a general approach in which the researcher takes whilst carrying out a given research project. Mack, et al., (2005) argues that qualitative research is work which seeks to answer a question, is systematically conducted, involves the collection of evidence and produces findings which were not previously available, whereas quantitative research involves the collection and collation of raw data to in order to statistical to support or contest existing work (Williams 2007).

The methodology used for this study is aimed to meet two main objectives. Firstly, analysis of the percentage errors in relation to actual and predicted output of wind turbines, both at the micro and macro level and secondly, determining possible future scenarios pertaining to wind energy and how the forecasting errors may affect the sector. Below details the basic formula pertaining to the calculation of percentage error.

Percentage Error Calculation:

$$\textbf{\textit{Percentage Error}} = \frac{\textbf{\textit{(Planned Production - Actual Production)}}}{\textbf{\textit{Actual Production}}} \times 100$$

Initially, data from several wind farms were to be included in this study. However, due to commercial sensitivity, only one of the wind farms approached for this research agreed to participate and share such sensitive data. Due to confidentiality and data protection, the farm will not be named throughout this work and will be referred to as 'site X'. Furthermore, a review of the correlations between predicted and actual output was carried out for this study. The collated data used is available in the supplementary material.

For the purpose of the reader, the results and data will refer to Meggawatt hour (MWh) which describes the power generated by a wind turbine. This power is generally determined by considering the power curve of the wind turbine and wind speed over a given time series. The electricity market then buys and sells these MWh of generated power as an economic commodity.

2.1 Data utilised for this research project came from two sources:

1. Wind farm (site X) - A leading private international energy company, who have a wind farm located in the West of Ireland were approached to participate in this research project regarding percentage error in wind energy forecasting. Following discussions with the Generation Operations Manager, the company agreed to share relevant data, providing that the company remained anonymous, for which a disclaimer was signed. The data provided consisted of collated monthly values from site X over a 12 month period from February 2013 to January 2014. The dataset acquired consisted of the predicted and actual output in MWh for the site X.

2. Eirgrid - To allow a detailed comparative study on a national level, data was also acquired from Eirgrid, the Transmissions System Operator (TSO) in Ireland, for the same time period of February 2013 to January 2014. Data from this source was acquired from a combination of values as published on their website and contact via email with Eirgrid Customer Support.

The dataset on a national level consisted of MW values at fifteen minute time series. This led to the need to convert such MW values to MWh for the purpose of this research to allow for an appropriate comparison between both datasets, source 1 and 2.

Site X's data was analysed first. Monthly predictions versus actual output were calculated to give a percentage error for each month, as well as the mean over the year. These findings are graphically illustrated in the next section. Eirgrid's data required that readings for each 15 minute time series were collated using Excel to give readings on an hourly, daily and monthly basis, before allowing a yearly figure. These findings are also graphically illustrated in the following section. For both datasets the method of calculating the mean percentage error over monthly and yearly time series helps reduce daily fluctuations and reduce overall percentage errors. The actual output value was used as a baseline to which the predicted output was statistically characterised.

It is important to note as part of the methodology that, as stated, it would have been preferable to have data from a selection of wind farms in Ireland. However, of the five companies approached only one consented to partake and disseminate company datasets. Thus, site X's dataset provide a small context in terms of micro percentage error profiles, whereas, Eirgrid represents the macro percentage error profile for Ireland.

3. Results:

As described in the methodology, in order to analysis the percentage errors regarding wind energy forecasting, a rigorous statistical assessment was conducted.

Figure 5 below illustrates the predicted and the actual wind energy output for Site X from February 2013 to January 2014. It details planned MWh for each month and actual MWh produced for each month. As can be seen on a monthly basis there is considerable variance between predicted wind energy output and actual output. July shows the largest percentage error at 116.5% between predicted and actual output, where the output was considerably overestimated, while September shows the lowest percentage error at -1.1% (Table 1). Despite monthly variances, once data was collated for the twelve month period as a whole, the wind farm yielded only a -0.36% percentage error for the year between planned and actual wind energy production.

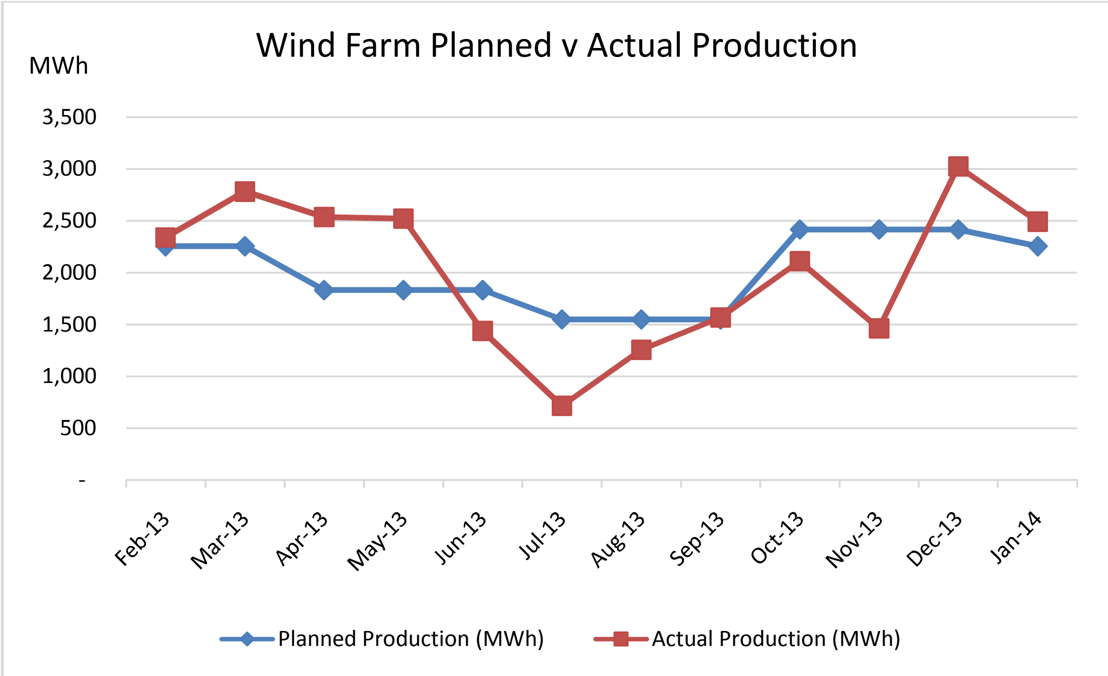


Figure 5

Site X

Having reported the dataset for the wind farm site X, the national data set from Eirgrid will now be detailed. As already stated in the previous section, data was collated from fifteen minute times series to allow for aggregated daily, and then monthly figures. As can be seen below there is some variance on a monthly basis between predicted wind energy output and actual output. On a national level, February 2013 yielded the largest percentage error at 15.2% between predicted and actual output, where the output was overestimated, while November 2013 shows the most accurate forecasting with a percentage error of only 0.4% (Table 2).

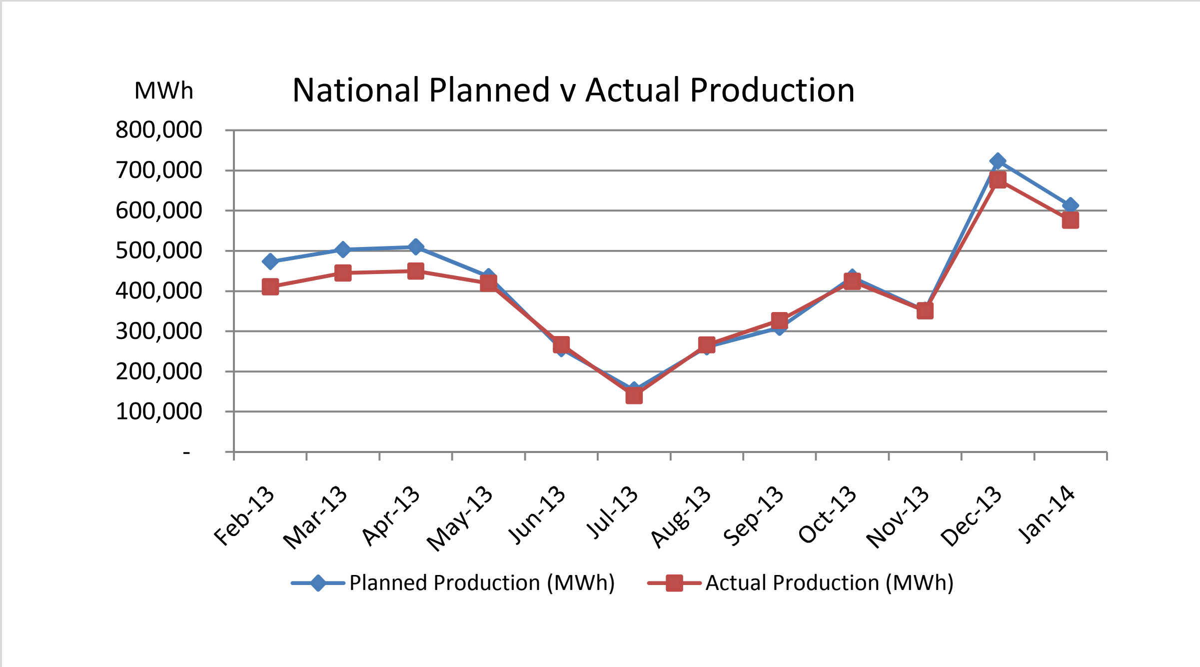


Figure 6

National Wind Energy

As stated in the methodology section, it was necessary to collate vast amounts of figures from fifteen minute intervals to collate daily, monthly and ultimately yearly figures for wind energy in Ireland. Figure 6 above illustrates graphically the trend for planned versus actual wind energy production nationally. As one can see the forecasting on a national level is relatively accurate overall. The largest percentage errors are found in the early and late months of the year where the actual wind energy production was less than the predicted output.

Upon completion of a series of tables representing the collated data over the period in question, it was possible to investigate the variances between forecasting on the macro and micro level. Figure 7 below graphs the percentage errors associated with both datasets, from Site X and from Eirgird. The blue line, which represents the wind farm (site X) percentage error, can be seen to vary considerably more than the national percentage error (red line) on a monthly basis. However, the aggregate of the percentage errors over the same twelve month period presents what appears to be that of highly accurate forecasts, with percentage errors of -0.36% and 5.7% respectively.

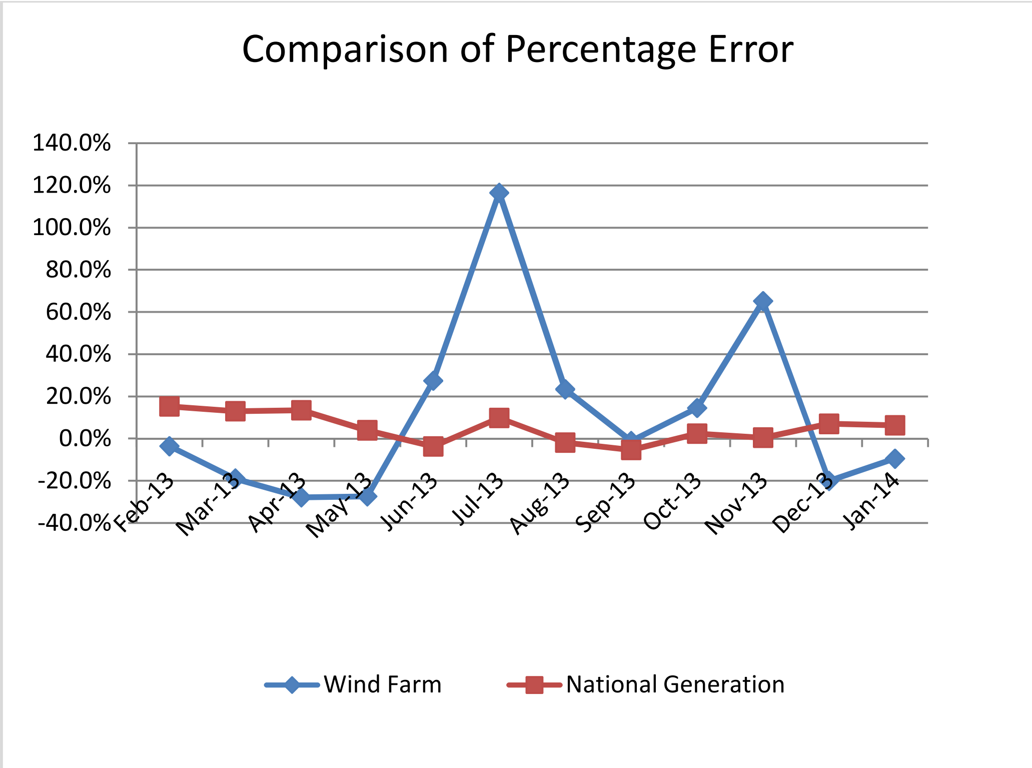


Figure 7

Comparison of Micro and Macro Percentage Error

Having examined the percentage error at both the micro and macro level over the twelve moth period the study will now analyse the percentage errors for two different time series. Firstly, Eirgrid's data was collated and calculated for the 1st of March 2013 (Figure 8) and was used to demonstrate the fluctuations experienced over a twenty four hour period. Secondly, the data was further analysed for the entire month of March (2013) (Figure 9).

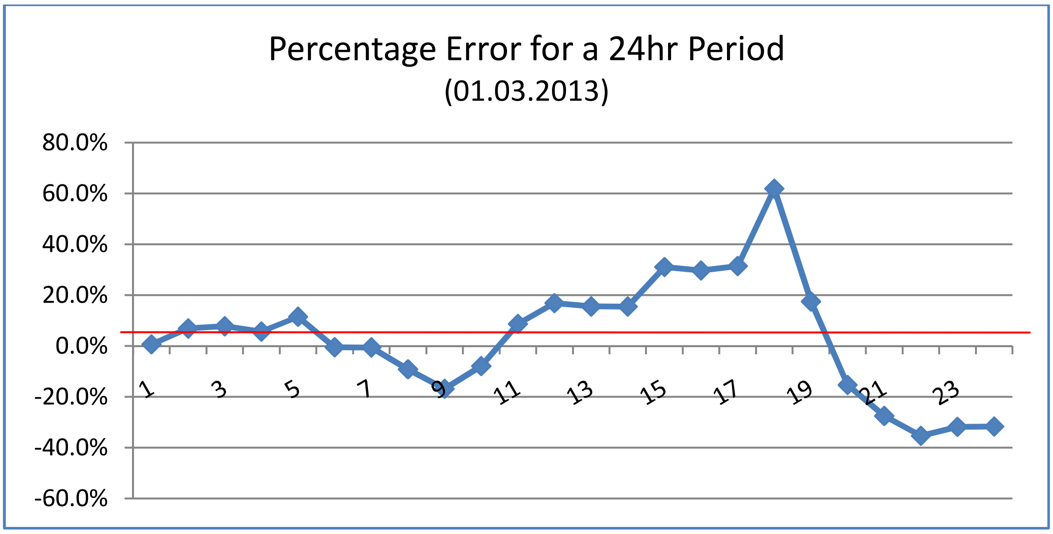


Figure 8

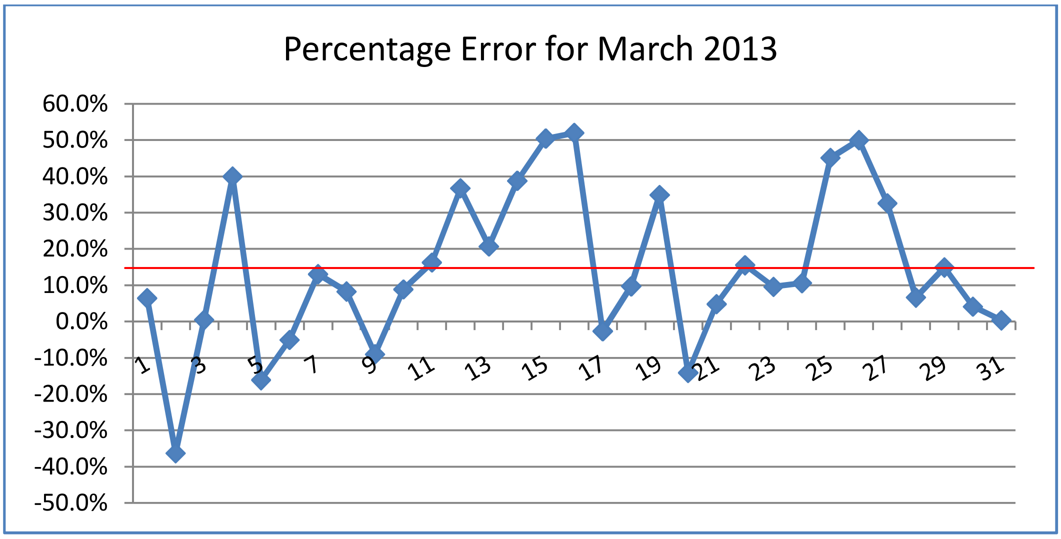


Figure 9

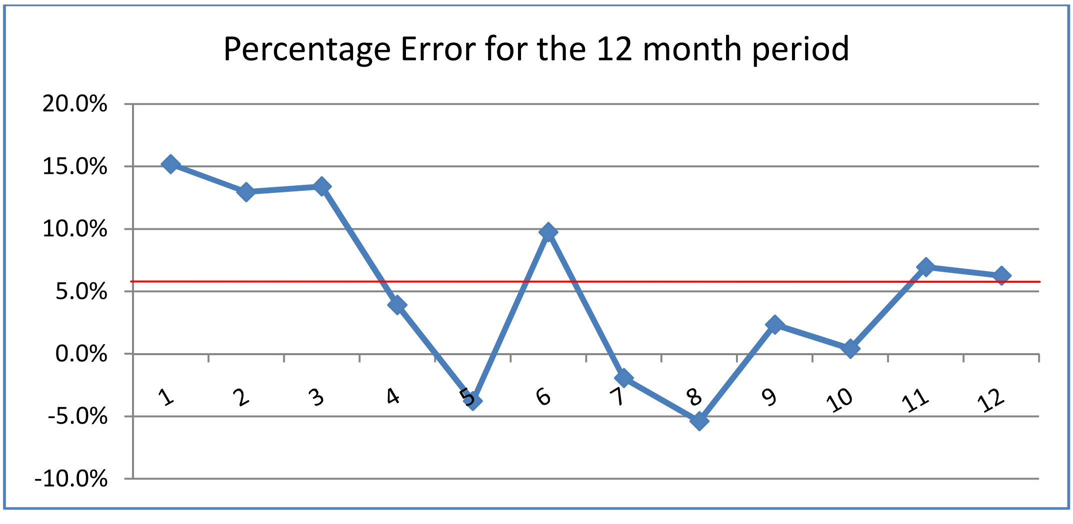


Figure 10

A significant finding from the above figures 8, 9, & 10 (Eirgrid's national dataset) and throughout the study is the appearance that a small percentage error is present across most time series. For figures 8, 9, & 10 the red line represents the total percentage error for the given time period. The findings for figures 8, 9, & 10 were 6.1%, 13% and 5.7% respectfully. The mean findings for the period show a relatively accurate forecast, but if an instantaneous point is selected throughout the period the accuracy decreases. This highlights that the forecast datasets contains less overall variability over an extended period compared to real time fluctuations.

The important point to take form this is that all of the time series values, for example the fifteen minute interval forecast, must be evaluated collectively, as no value itself gives a holistic overview of a generation system. Furthermore, governments, planners and developers take a much broader view of wind energy systems and inevitably look at output trends over very long periods, such as, twenty to twenty five year energy production. In relation to electrical systems planning and operational concerns, the shorter term forecasts are of greater concern due to traditional generation reserve requirements.

4. Discussion:

The aim of this research paper was to examine and analyse the potential percentage error in forecasting of wind energy using datasets from both a small wind farm in Ireland and from national figures provided by Eirgrid. Furthermore, to analyse the errors which occur in wind energy forecasting and to evaluate the overall performance of forecasting with the most significant results being presented. To achieve this, a literature review of wind energy, specifically forecasting and prediction error, was needed to indentify the associated effects of errors throughout the sector, with the importance of forecasting which was previously discussed in the introduction of this paper. The statistical analysis for this paper demonstrated that while on the smaller wind farm there was considerable variance on a monthly basis, over the twelve month period the percentage error was -0.36%. Based on Eirgrid's larger dataset, variance on a monthly basis was less, but with an overall yearly percentage error of 5.7%. The variances across both were almost always that of over prediction regarding wind energy output. However, it should be noted that the installed capacity of site X (being relatively small) may have distorted the findings and given the appearance of a more accurate forecast over the twelve month period.

In discussion of the results, it is important to indentify and understand the variances which tend to cause the errors associated with wind energy forecasts. In fact, as seen in this research, patterns tend to emerge which show a correlation between this fluctuating resource percentage errors.

4.1 Error Assessment:

Accurate wind energy forecasting will allow establishment of an appropriate generation mix prior to significant variations in the wind (Letcher 2008). Bielecki (2010) contends that wind energy forecasts are not completely accurate, but they have been shown to reduce the overall integration costs for large scale development.

The very nature of wind energy causes variability and uncertainty in electrical networks. Thus, forecasting and percentage errors are essential to wind energy integration, especially as installed capacity is estimated to increase substantially in the coming years. Even though this renewable energy resource is mature and there is vast knowledge and experience throughout the sector, there is still no single forecasting method which encompasses all of the complexities associated with this natural resource. Madsen, H., et al. (2004) contends that currently there is no universal means of evaluating forecast performance.

The overall percentage errors for the wind farm and national wind generation were shown in figure 7 for comparison. The plotted points illustrate the scale of fluctuations in forecasting at both the micro and macro capacities. As shown, the wind farm forecasting tends to vary considerably more than the national generation, with far less deviation at the macro level. EWEA (2007) contends that since not all wind farms in a region experience the same average wind speed and since the error made by the NWP is temporally and spatially distributed, the error for forecasting on the macro is smaller than that of the micro level. Furthermore, it is believed that there are two effects which improve the accuracy of the percentage error in forecasting at the macro level. Firstly, the generation is already smoother due to the uncorrelated frequencies of the micro generation profiles. Secondly, the percentage errors are uncorrelated on an even smaller length scale, as generation correlation tends to vanish on a length scale of approximately seven hundred and fifty kilometres (EWEA 2007).

4.2 Performance of Forecasts:

As mentioned previously, the variability of wind energy presents many challenges. However, there are several inaccuracies which lead to errors in forecasting. For example, there are inaccuracies in relation to the weather models, also weather to power conversion and contrasted or curtailments with individual wind farms (Eirgrid 2011). Furthermore, factors such as energy loss caused by wake loss, availability and turbine performance must also be included with the latter relating directly to individual turbines and associated power curves. In fact, power curves also provide a substantial level of percentage errors and are, at times interpreted incorrectly. Power curves are based upon turbine output plotted against wind speed in an ideal scenario. However, in reality turbines are installed in locations which experience turbulence and may have complex terrain, thus, causing the wind to hit the rotor from varying directions. In fact, a turbine positioned at multiple locations could have different outputs for the same mean wind speed value.

4.3 Improving Forecasting:

As the wind energy sectors grows and secures a larger market share of global electricity networks, there is an urgent need to minimise the percentage errors in relation to forecasting. This could be addressed by introducing more regular accuracy reviews, by offering vendor performance incentives, or simply allowing a larger error within the forecasts. As shown, the raw data highlights over prediction for the majority of scenarios modelled. However, in the opinion of the author, the main area which could potentially revolutionise current forecasting would be a more collective and collaborative dissemination of data, similar to the SafeWind Project and the Anemos.plus Project. As was the case with this study, it was extremely difficult to acquire actual raw data, as it tends to be commercially sensitive. However, it is not surprising that such data is being held with strict confidentiality given the colossal amount of cost involved with project developments. Irrespective of the scale of monies involved, for the sector to progressively advance, there needs to be a functioning synergy between industry, government and academia.

Assessing percentage errors involves taking a holistic approach to wind farm performance. In fact, this study highlights that the errors on a monthly basis can be quite high at times, in some cases above 100%. Currently, industry wind forecasting models used are somewhere in the region of 61% accurate (Blackledge n.d.).

In general, wind forecasting errors were presumed to follow a normal distribution. However, since the European SafeWind Project, which was completed in 2102, there has been an improvement in wind energy predictability. The last two decades have witnessed much research and development in the area of wind energy forecasting which has lead to several operational tools. In spite of this, there are still improvements to be made in relation to the overall accuracy of forecasts. Furthermore, with wind penetration predicted to rise in the coming years, there needs to be a European vision of forecasting alongside progressive planning and policy.

The first stage in sustainable large scale wind integration is enabling collaborative forecasting. It is estimated that global installed wind capacity will continue to rise rapidly over the next decades, 2,500 GW by 2030 and a staggering 4,800 GW by 2050 (IEA 2013). Thus, accurate forecasting becomes a critical tool as wind energy increases. In fact, Spain is leading the way in relation to forecasting and has reduced day-ahead errors by one third (IEA 2013). If the scenario of 2050 is achieved, it would be expected to yield 12,651 TWh from the installed capacity (IEA 2013). Moreover, if the national percentage error for the twelve month period, as calculated in this study, is applied to the 2050 scenario, that would result in a global over prediction of 683 TWh of wind energy. This could potentially have detrimental effects on both infrastructures and electricity grids internationally. At a European level, the Energy Roadmap 2050 was adopted in 2011 to ensure a framework was in place to facilitate the decarbonisation of the sector. In relation to Ireland's total installed wind energy capacity, since 2003 there has been year on year growth of approximately 200 MW (DCENR 2012). If this growth is used to estimate a future scenario, this would see Ireland with a potential installed capacity of 9.5 GW. Furthermore, if the national percentage error is again applied to the future scenarios of 2020, 2030 and 2050 which have been derived from DCENR (2012) (Table 6), this would result in an over prediction of 482, 766 and 1,348 GWh respectfully.

In summary, the results of this paper showed variances in varying percentage errors over daily and monthly periods with over prediction being the main culprit, yet percentage error over a twelve month period was greatly reduced. This discussion has stated why the small wind farm variances were more likely to be greater than the large scale national Eirgrid, and also detailed why forecasting is such an important topic, especially for the coming years and next generation of wind energy production.

5. Conclusion:

There is a general consensus that renewable energy, specifically wind energy, will play an important role in Ireland's future energy supply, more so as the dependency upon imported fossil fuels increases. Moreover, due to recent increases in gas, the gap between generation costs is narrowing. Thus, understanding the variability of wind energy and reducing forecasting errors is an important step to ensuring security of supply. Boyle (2009) contends that even with the large growth in wind energy the total conventional plant capacity will never be less than the peak load.

This study sought to demonstrate a rigorous analysis of the trends associated with wind energy forecasting as experienced with typical wind farms (micro level) and also at a national level (macro level). A number of analytical measures have been implemented to allow a better understanding of forecasting errors over a variety of different time series.

The evaluation criteria, which was discussed in the methodology section, has allowed this study to evaluate a number of forecast performances and identify specific patterns which have emerged in the overall forecast composition and related error behaviours. Furthermore, the methodical approach used throughout this study and the results obtained can now be directly applied to similar output datasets to analyse the associated forecasting percentage errors.

The results of this study suggest that there are relatively small statistical percentage errors in relation to modern wind energy forecasting over long periods of time. However, with such large public and private financial investment in the sector, and the fact that installed capacity is estimated to increase exponentially over the coming decades, every opportunity much be seized to reduce the percentage errors. As stated by Lund (2010) the design of renewable energy systems involves three major technological changes; energy saving on the demand side, replacement of fossil fuels and finally, efficiency improvements in the energy production.

6. Future Works:

This study, which was based primarily on two datasets, raised many questions for the future of percentage errors and modern forecasting in relation to wind energy. In the opinion of the author, it would be very beneficial to conduct a similar study using several additional datasets. Moreover, the dissemination of data and the potential benefits available to the sector appear great. Therefore, does Ireland need a professional body to foster research projects which could lead to improved accuracy, such as SafeWind? Finally, another area which could be examined further would be the forecast methods which are being implemented throughout industry, to gauge potential improvements.

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Appendix:

Month	Planned Production (MWh)	Actual Production (MWh)	% Error
Feb-13	2,255	2,339	-3.6%
Mar-13	2,255	2,782	-18.9%
Apr-13	1,832	2,538	-27.8%
May-13	1,832	2,521	-27.3%
Jun-13	1,832	1,438	27.4%
Jul-13	1,550	716	116.5%
Aug-13	1,550	1,256	23.4%
Sep-13	1,550	1,567	-1.1%
Oct-13	2,416	2,110	14.5%
Nov-13	2,416	1,463	65.2%
Dec-13	2,416	3,024	-20.1%
Jan-14	2,255	2,492	-9.5%
Year Total	**24,159**	**24,247**	**-0.36%**

Table 1

Planned and Actual Output for the Twelve Month Period

Interpreted from Site X's data

(see Figure 5)

Month	Planned Production (MWh)	Actual Production (MWh)	% Error
Feb-13	473,390	410,974	15.2%
Mar-13	503,960	445,374	13.2%
Apr-13	510,016	449,721	13.4%
May-13	436,162	419,714	3.9%
Jun-13	256,828	266,884	-3.8%
Jul-13	154,210	140,510	9.8%
Aug-13	261,393	266,533	-1.9%
Sep-13	309,576	327,164	-5.4%
Oct-13	434,586	424,628	2.3%
Nov-13	352,560	351,090	0.4%
Dec-13	723,611	676,595	6.9%
Jan-14	612,463	576,377	6.3%
Year Total	**5,028,755**	**4,755,563**	**5.7%**

Table 2

Planned and Actual Output for the Twelve Month Period

Interpreted from Eirgrid's data

(see Figure 6)

Hour	Planned Production (MWh)	Actual Production (MWh)	% Error
1	312	310	0.6%
2	280	262	6.9%
3	250	232	7.8%
4	224	212	5.7%
5	204	183	11.5%
6	185	186	-0.5%
7	168	169	-0.6%
8	148	163	-9.2%
9	128	154	-16.9%
10	128	139	-7.9%
11	163	150	8.7%
12	201	172	16.9%
13	223	193	15.5%
14	216	187	15.5%
15	211	161	31.1%
16	201	155	29.7%
17	188	143	31.5%
18	170	105	61.9%
19	94	80	17.5%
20	77	91	-15.4%
21	63	87	-27.6%
22	53	82	-35.4%
23	47	69	-31.9%
24	43	63	-31.7%
	3977	**3748**	**6.1%**

Table 3

Planned and Actual Output for 01.03.2013

Interpreted from Eirgrid's data

(see Figure 8)

Day	Planned Production (MWh)	Actual Production (MWh)	% Error
1	3977	3736	6.5%
2	526	825	-36.2%
3	4671	4649	0.5%
4	7108	5079	39.9%
5	8052	9597	-16.1%
6	15054	15855	-5.1%
7	23188	20509	13.1%
8	20580	19005	8.3%
9	18523	20355	-9.0%
10	32072	29458	8.9%
11	28748	24724	16.3%
12	14337	10487	36.7%
13	8971	7432	20.7%
14	14187	10223	38.8%
15	16622	11051	50.4%
16	4226	2781	52.0%
17	9446	9701	-2.6%
18	5414	4934	9.7%
19	8754	6491	34.9%
20	4253	4951	-14.1%
21	34455	32867	4.8%
22	32616	28228	15.5%
23	28619	26115	9.6%
24	27324	24702	10.6%
25	24702	17025	45.1%
26	14392	9596	50.0%
27	8860	6682	32.6%
28	17162	16093	6.6%
29	26015	22637	14.9%
30	13234	12711	4.1%
31	26972	26875	0.4%
	503060	**445374**	**13.0%**

Table 4

Planned and Actual Output for March 2013

Interpreted from Eirgrid's data

(see Figure 9)

Month	Planned Production (MWh)	Actual Production (MWh)	% Error
Feb-13	473,390	410,974	15.2%
Mar-13	503,960	445,374	13.2%
Apr-13	510,016	449,721	13.4%
May-13	436,162	419,714	3.9%
Jun-13	256,828	266,884	-3.8%
Jul-13	154,210	140,510	9.8%
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Oct-13	434,586	424,628	2.3%
Nov-13	352,560	351,090	0.4%
Dec-13	723,611	676,595	6.9%
Jan-14	612,463	576,377	6.3%
Year Total	**5,028,755**	**4,755,563**	**5.7%**

Table 5

Planned and Actual Output for the Twelve Month Period

Interpreted from Eirgrid's data

(see Figure 10)

Year	MW		Year	MW
2005	500		2028	5000
2006	750		2029	5200
2007	880		2030	5400
2008	1100		2031	5600
2009	1290		2032	5800
2010	1400		2033	6000
2011	1590		2034	6200
2012	1800		2035	6400
2013	2000		2036	6600
2014	2200		2037	6800
2015	2400		2038	7000
2016	2600		2039	7200
2017	2800		2040	7400
2018	3000		2041	7600
2019	3200		2042	7800
2020	3400		2043	8000
2021	3600		2044	8200
2022	3800		2045	8400
2023	4000		2046	8600
2024	4200		2047	8800
2025	4400		2048	9000
2026	4600		2049	9200
2027	4800		2050	9400

Table 6

Estimated Installed Wind Capacity in Ireland to 2050

Derived from DCENR 2012