IMPACT OF INTERMITTENCY:

HOW WIND VARIABILITY COULD CHANGE THE SHAPE OF THE BRITISH AND IRISH ELECTRICITY MARKETS

Summary report

July 2009

'The wind flapped loose, the wind was still,
Shaken out dead from tree and hill:
I had walked on at the wind's will
I sat now, for the wind was still.'
Dante Gabriel Rossetti, The Woodspurge

IMPACT OF INTERMITTENCY

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Front cover shows a wind farm at Black Hill, UK (image courtesy of RES).

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1. INTRODUCTION

Both the UK and the Republic of Ireland have set ambitious targets to reduce the countries' carbon dioxide emissions. There is a general expectation that wind generation will bear the brunt of the burden, especially as both countries drive towards the national targets set out in the EU Renewables Directive. Estimates of the amount of wind required to meet the countries' targets range between 6–8GW on the island of Ireland and 35–45GW in Great Britain by 2030, although there remains much speculation on the pathway leading to this date.

With this amount of wind generation, the future electricity markets will be very different to those of today: instead of thermal power stations dominating the system, the market will be dominated by large amounts of price-insensitive nuclear and wind power, combined with highly intermittent output from the windfarms.

The Irish and British electricity markets, the Single Electricity Market (SEM) and British Electricity Transmission and Trading (BETTA) respectively differ significantly in their design – the SEM having a capacity payment and a pool-type structure as opposed to the bilateral trading philosophy of BETTA. Accommodating large amounts of wind will test them in very different ways, and provide the electricity industry with a rare opportunity to 'compare and contrast'.

There are several more compelling reasons to investigate the likely impact of wind in the British and Irish markets in far more detail:

- The impact on the markets as opposed to the physical system: their character, the prices, volatilities and attractiveness for investors – in other words how the markets would function – has largely been the subject of conjecture;
- Detailed behaviour and patterns of the wind and weather and the way it is correlated between different locations in the two islands needs far better understanding; and
- Hour by hour changes – ramping up and down in response to demand – have not been considered in previous studies, but power systems need to work in real time, and the impact of holding sufficient reserve for the wind will be very important.

So to understand the likely nature of the impact of the wind on both markets it is important to answer the following questions:

- What is the wind output likely to look like in the future and what is the impact on the thermal plant portfolio?
- How will market prices be affected? Will too much wind collapse prices to zero?
- Can interconnection provide a golden bullet?
- What sort of response and reserve might be needed on the system to maintain current reliability standards?
- Can the market arrangements survive in a world with a large amount of wind, in both BETTA and the SEM?
- Are there sufficient and appropriate investment signals to attract suitable power station investments?

This report summarises the first study of its kind to provide a comprehensive vision of the shape of the British and Irish electricity markets when they both include the large amounts of wind generation to which policymakers aspire.

The results described in this summary report are the output of a year-long project with a budget of almost a million pounds; the study has assembled an unprecedented quantity of wind data, built completely new electricity market models, and has entailed more than 20,000 hours of effort.

Leading companies involved in both markets have provided invaluable input, along with System Operators, Regulators and Government departments.

1.1 Acknowledgements

The project has been a major undertaking for a large team of people and would not have been possible without the support and advice of the following founder members: Centrica, DONG Energy, EirGrid, ESBI, National Grid, and RES. Their data and support, along with those of the Meteorological Office and Met Éireann have provided us with a vast resource to build on.

The combination of organisations in Ireland and Britain has been particularly powerful: Ireland swings on the British market whereas the policies and data from Ireland have provided valuable data and lessons.

2. CHARACTERISING THE WIND

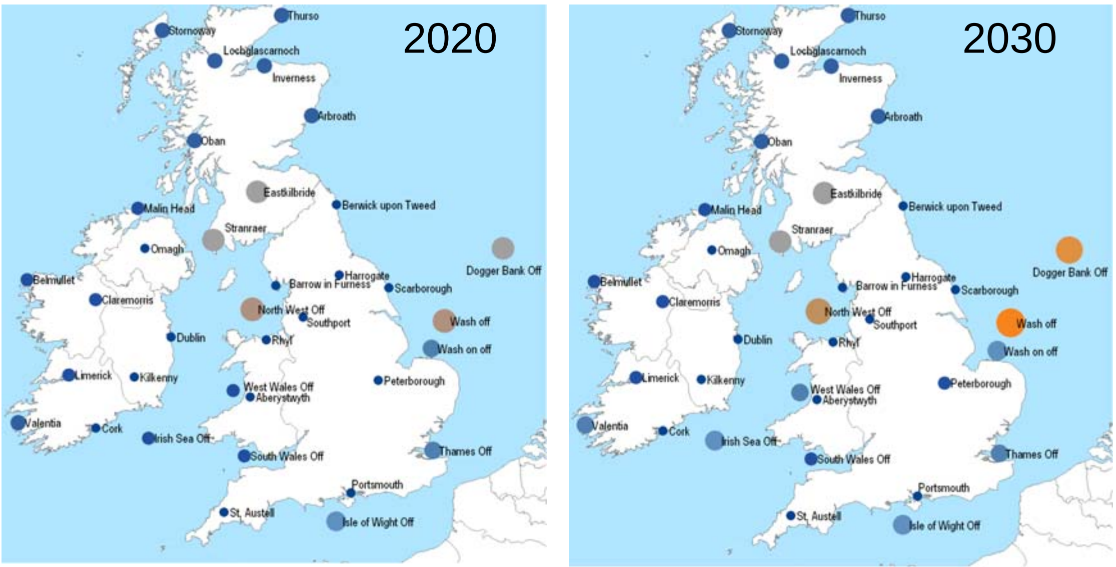
2.1 Introduction

Properly modelling the output from windfarms in the future needed a comprehensive understanding of historical wind patterns at all the locations where windfarms are likely to be built. Data needed to be analysed at an hourly basis so that we could properly understand historical correlations between different locations and then extrapolate them to the hub-height of the wind turbines, and then compute these relationships to build complex, statistical models for future years using Monte Carlo modelling techniques.

An unprecedented quantity of historical data has been used in this project – taking hourly data for each of the years 2000–2007 for observations in 36 different locations – over 2.5 million data points.

A core scenario of build-out of wind capacity was developed with the guidance of the Steering Committee factoring in views such as likely licensing rounds and advantageous wind resources, as shown in Figure 1 below:

Figure 1 – Location of installed wind capacity



GB Capacity: 33GW
SEM Capacity: 6GW

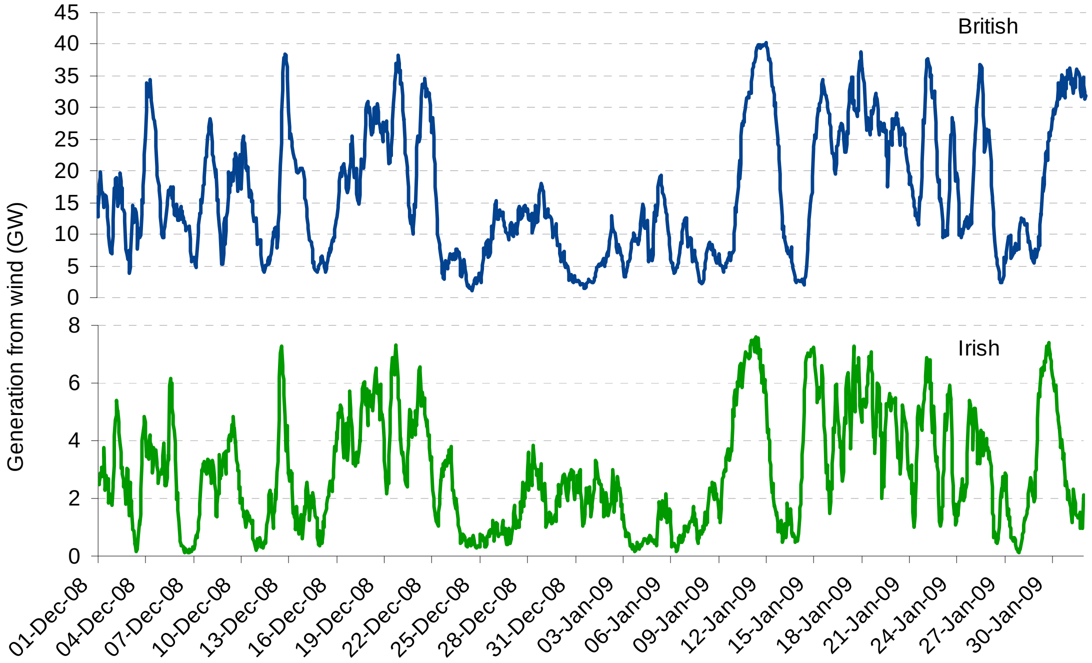
GB Capacity: 43GW
SEM Capacity: 8GW

Installed capacity (MW) 1000 5000 8000

We also factored in additional 'intermittent' generation from potential tidal barrage developments in the Severn Estuary. Although the tidal flows are far more predictable, the changing output from such generation sources add significantly to the total of intermittent generation in the market.

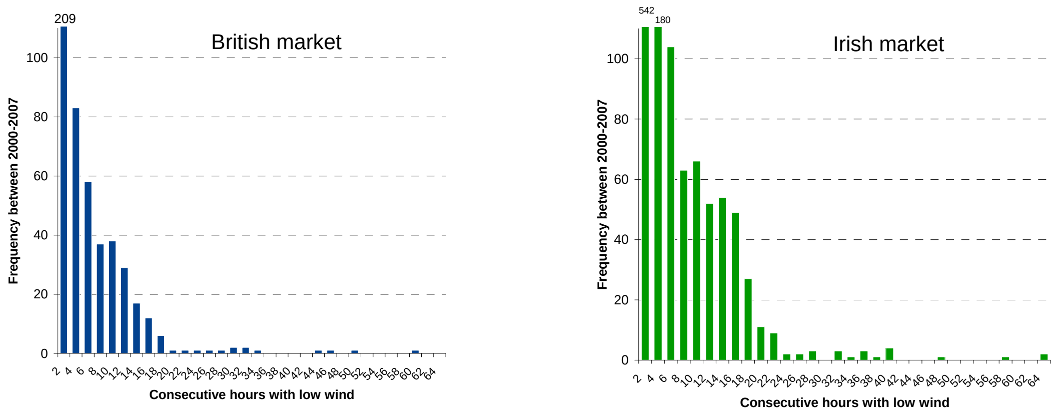
After checking that our wind modelling produced very close results with historical outputs, we were able to construct forecasts of the wind generation in future years based on the historical weather patterns. For example Figure 2 below shows the pattern of wind generation either side of the New Year in 2030 based on 2008/9 weather. Both the uncertainty and the correlations in weather between the two markets are apparent.

Figure 2 – Example wind generation profiles for 2030 with wind of 2008/09



In understanding the statistical nature of the wind output, we were now able to examine the very important 'tails' of low and high wind output: for example Figure 3 illustrates the distribution of the all-important 'low wind' periods (defined as when output from wind is less than 5% of its capacity) when we base 2020 on the entirety of all eight data years. There has been a great deal of speculation on the frequency of such events, and now we are able to quantify and characterise them. This chart shows that between 2000–2007 there were 209 hours in the British market and 542 hours in the Irish market when the wind generation was below 5% of its maximum capacity for a single hour only - and just one period of almost three days at this low level.

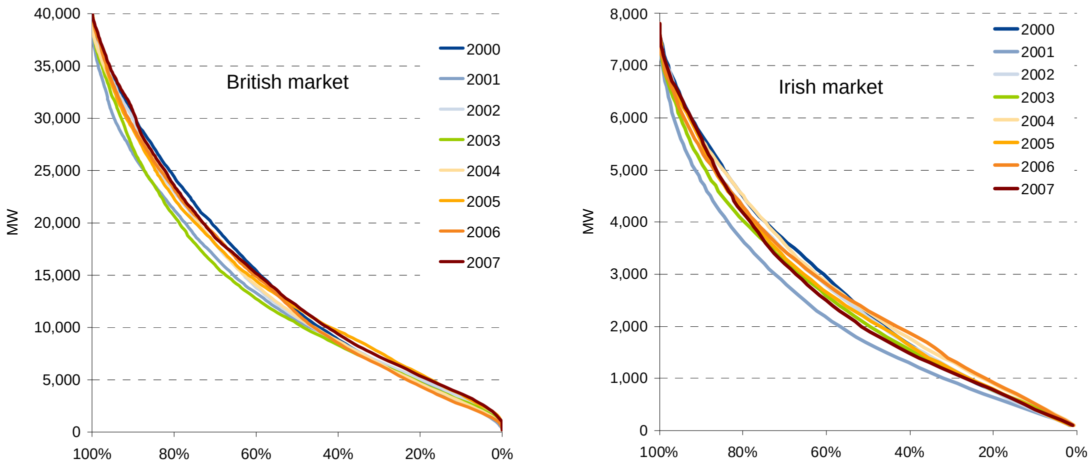
Figure 3 – Count of low wind energy periods in 2020



Each band represents a two-hour period

We found a significant amount of variation of wind output from year to year based on our eight sample years. Figure 4 below shows the duration curves of wind output in our sample years (duration curves show the percentage of time in a year when output is above a certain level). The differences in shape from one year to the next are significant – at a higher level, over these years the *annual* output varies by almost 25% in the Irish market, and around 13% in the British market.

Figure 4 – Variation of wind output year on year (British and Irish)

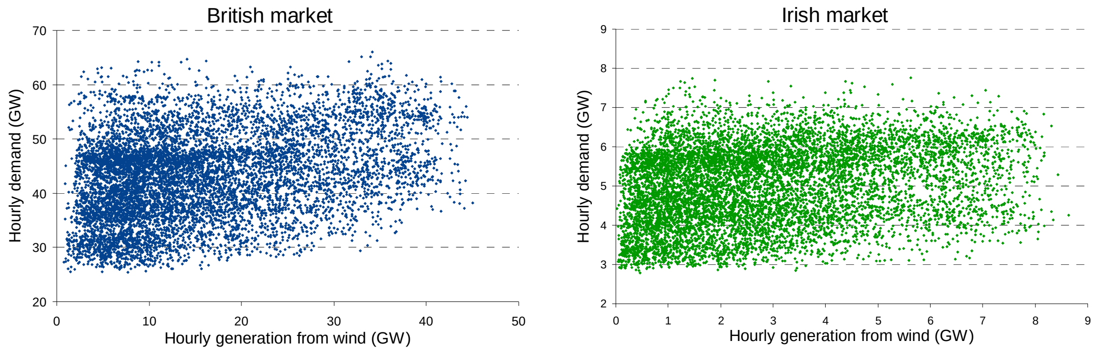


2.2 Wind and demand

The next stage of the analysis was to subtract the wind output from the electricity demand to examine the demand pattern that the remaining power stations will have to meet. Previous analyses have concentrated on determining a 'capacity factor' for the wind – in other words, the likely equivalent proportion of thermal capacity. However a high wind market of the future cannot be considered in terms of averages. Instead our analysis concentrated in understanding the probabilities of extremes occurring.

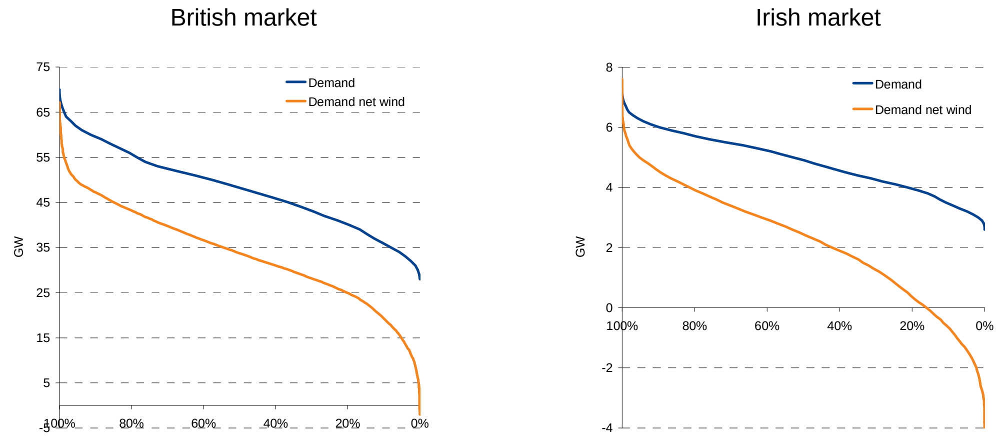
Several commentators have suggested that high wind conditions generally coincide with high demand, but Figure 5 below shows how poorly demand and wind generation are correlated in both markets.

Figure 5 – Correlation between wind and demand (2030, weather of 2002)



Our models were able to generate detailed patterns of 'demand net wind', and Figure 6 shows the dramatic impact on the demand duration curves when we subtract the output of the wind from the total demand. These charts illustrate the proportion of a year that system demand is above a given level: the upper line shows the character of the gross system, and the lower line is the remainder when the intermittent generation is subtracted. It is the lower line that the other power stations on the system will have to supply.

Figure 6 – Demand duration curves for both markets in 2030

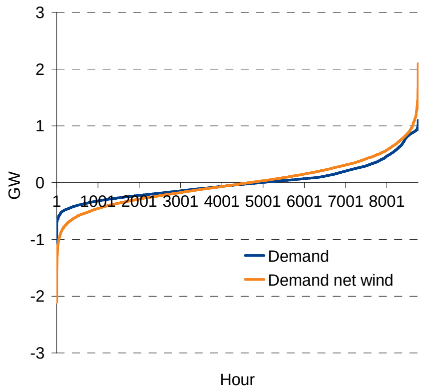


Installed capacity and demand from Core scenario.

Much of the remainder of this report examines the profound impact on the markets of the change that these graphs illustrate. However, there is one more important aspect that we were also keen to investigate, namely the dynamics of the system – how <u>fast</u> can the wind change.

Our analysis was able to quantify this in some detail by examining likely ‘ramping rates’ over different timescales. As an example Figure 7 below shows the duration curve for one hour ahead for the Irish market, which is a good indication of how often additional plant will be needed or not needed within a one-hour timescale. We were able to look at this over other timescales and so understand how much plant is needed to be kept in readiness to meet the changing wind output.

Figure 7 – One-hour ramping duration curve for the Irish market (2030)



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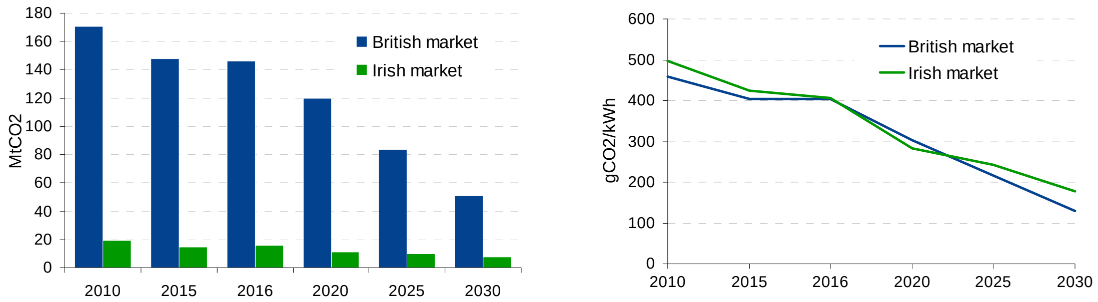
3. HOW WIND OUTPUT MIXES WITH CONVENTIONAL POWER STATIONS

In order to examine the impacts of high amounts of wind in the Irish and British markets we centred our analysis around a 'Core' scenario. This is not a forecast; it is deliberately designed to examine the impact of large amounts of wind generation in the market, while meeting current system security standards and tracking towards accepted decarbonisation levels. To accentuate the impact, the Core scenario deliberately considered modest demand growth and large amounts of nuclear build. This scenario does not represent our 'base case' or most likely outcome for the future – rather it provides a stress-test for exploring a future with intermittent generation. Figure 8 below shows the carbon emissions trends for the Core scenario.

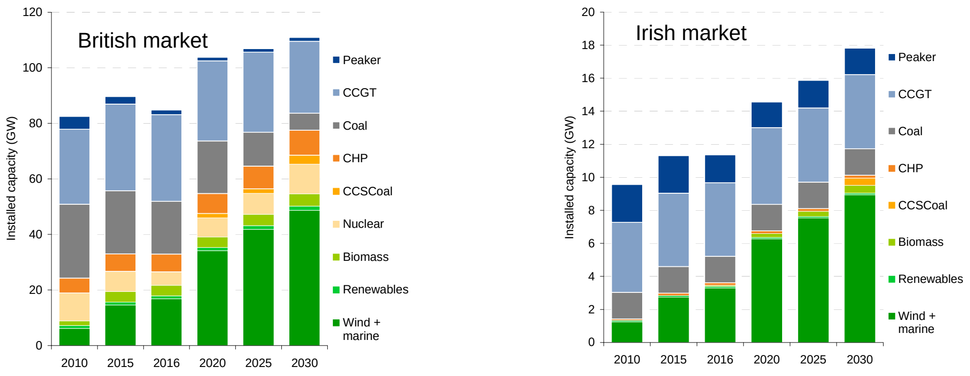
Figure 8 – Carbon emissions in Core Scenario



We were particularly interested in the way that thermal plant would have to operate to supply the 'demand net wind' in a way which maintains the system reliability at current levels. Furthermore in order to show the longer term market trends, our projections model separately the Irish and British market rules, as they provide quite different economic signals for new plant. Many commentators describe the generation-demand balance in terms of 'capacity margins', but such metrics do not work well in high wind systems, where sufficient capacity needs to be measured in terms of system reliability instead.

The first step of building the Core scenario was to fix the build out of wind, nuclear and other low carbon generation sources. The consequent development of the plant capacity over the years to 2030 in the Core scenario in each market is shown in Figure 9 below, and illustrates our findings on the balance of thermal and wind capacity required to meet system security standards as the amount of wind capacity grows. This chart shows the actual capacity on the system in these years – in practice some existing plant will be retiring and need replacing.

Figure 9 – Installed capacity by plant type in the Core scenario

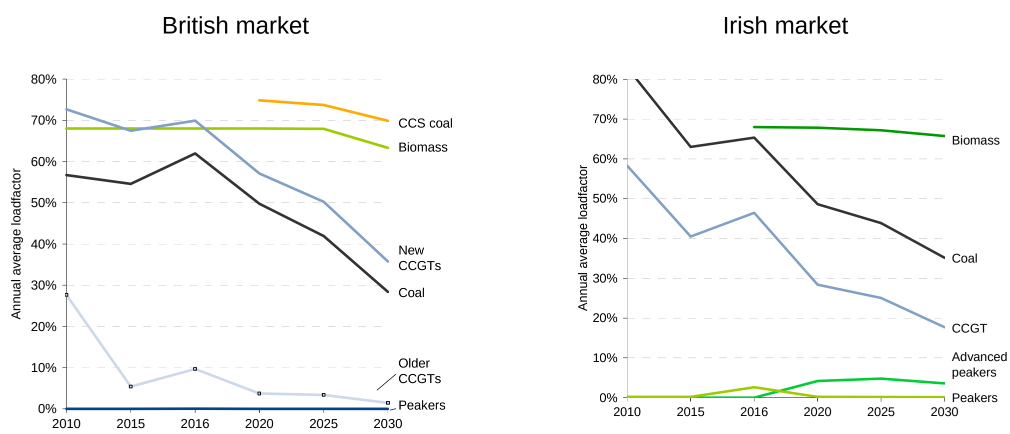


Note: 'Peaker' includes gas and oil-fired steam-cycle plant as well as new and old GT plants.

Based on our understanding of the dynamics of the power stations, in both markets the thermal plant and interconnectors appear to be able to deal with the dynamic requirements of the wind (although there are some years where this is quite tight).

As expected the running regime for the thermal plant is altered drastically as it is 'squeezed' into its own intermittent patterns. Figure 10 indicates the load factors projected in the Core scenario by plant type.

Figure 10 – Plant load factors



However, the load factors only tell part of the picture, as in practice the operational regimes of the plant at even quite high load factors are highly irregular.

It is quite possible that, particularly for the CCGT fleet, plant availability will be reduced or need higher maintenance costs when faced with running regimes like this: lower availability would require additional capacity to maintain system reliability standards.

In the context of capacity make up, we found that the Irish market relies heavily on the interconnectors to the British market, with these taking significant load flow variations in response to the wind. We discuss interconnectors in more detail later on in this document.

This study was able to examine the impact of alternative market rules on investment drivers for new capacity. We found that SEM naturally builds OCGTs to maintain suitable dynamic response – but BETTA has real difficulty in providing incentives for peaking plant and is likely to favour CCGTs instead.

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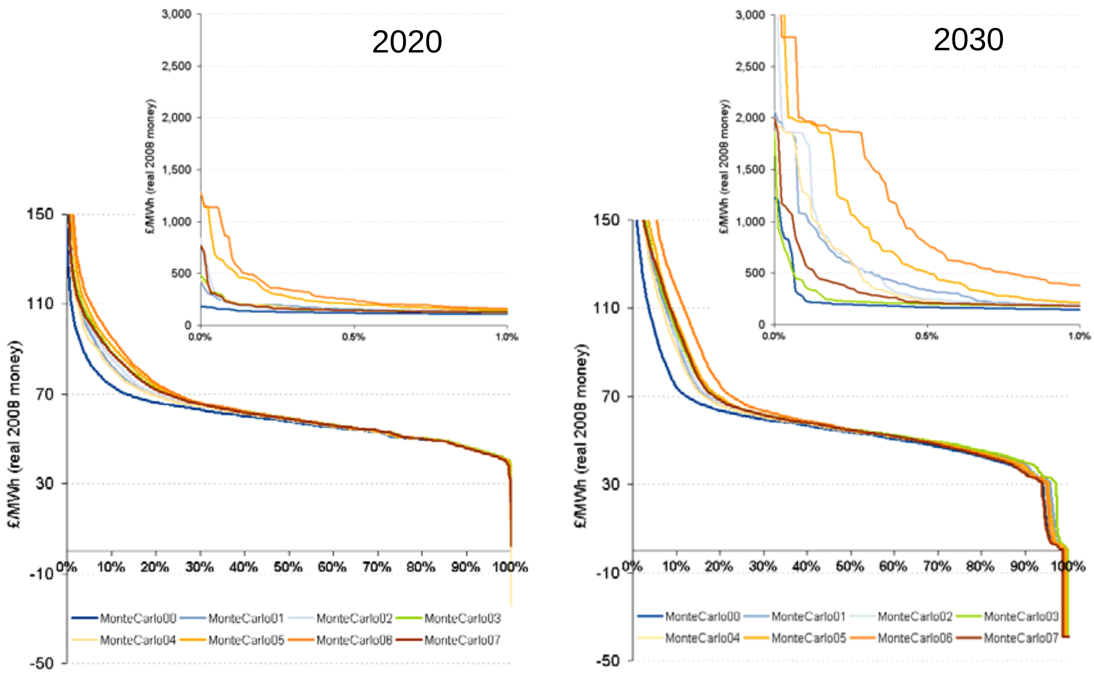
4. OUTLOOK FOR MARKET PRICES

Understanding how prices will change hour-by-hour is particularly important in anticipating how wind can change markets. Sophisticated computer models of all the generating plant in the British and Irish markets were used to simulate how prices may evolve in the future.

With the higher wind, although market prices were depressed somewhat, they also become far more ‘spikey’ with increased periods of extremely high or very low, sometimes negative, prices. This is because the system will alternate between having too much wind generation, and being far tighter when there is little wind.

Figure 11 – Price duration curve for the British market



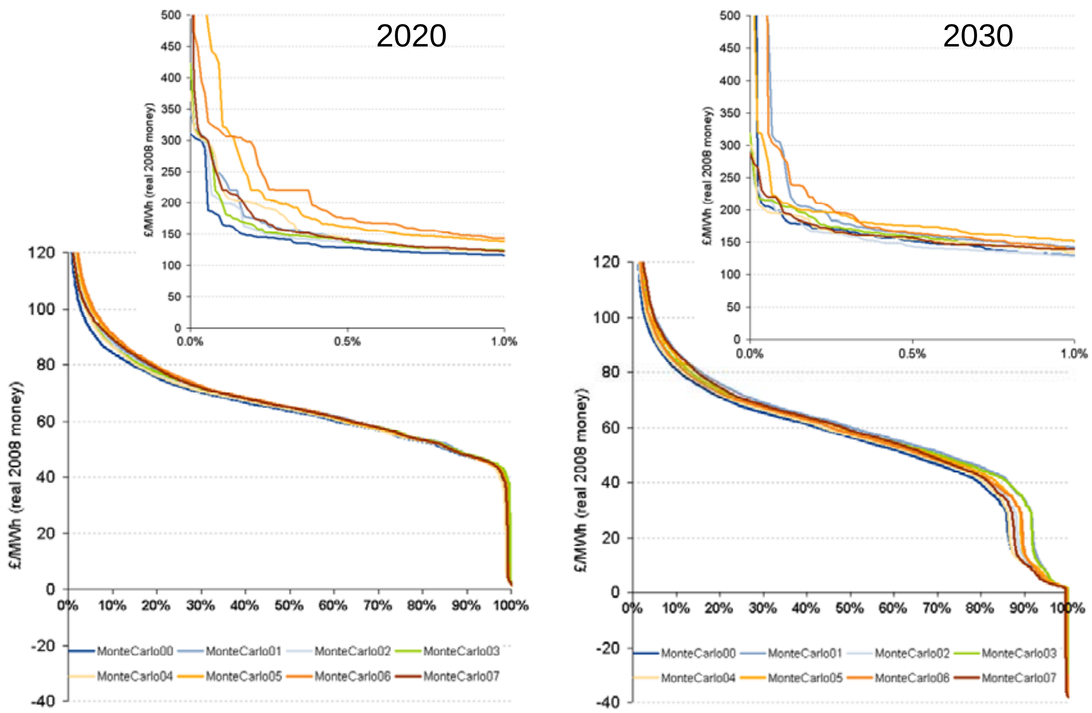
Prices spike to almost £1300/MWh in 2020, and almost £8,000/MWh in 2030.

Figure 11 shows a price duration curve for the British market: effectively all prices in one year stacked from highest to lowest. Each coloured line represents one ‘Monte Carlo’ simulation. In 2020, with wide system margins, there are a few periods with zero prices, and there are very high prices for some periods. By 2030, with even more wind on the system, the distribution of prices becomes even more extreme. There will even be periods of negative prices arising from the wind plant valuing its output at the opportunity cost of –1 ROC, as well as very short periods with prices almost at £8,000/MWh.

However, these spikes in price are necessary for the market to operate. Without them, generators that only run a few hours each year cannot make sufficient returns.

We find that the commercial risk of operating in this market is far greater than currently. It will be highly uncertain how high prices might rise, and depending on the interaction between wind and demand, in any given year these price spikes simply may not occur. This is shown by the different lines in Figure 11 – in some simulations there are quite low prices, whilst in others there are much more extreme prices.

Figure 12 – Price duration curve in the Irish market



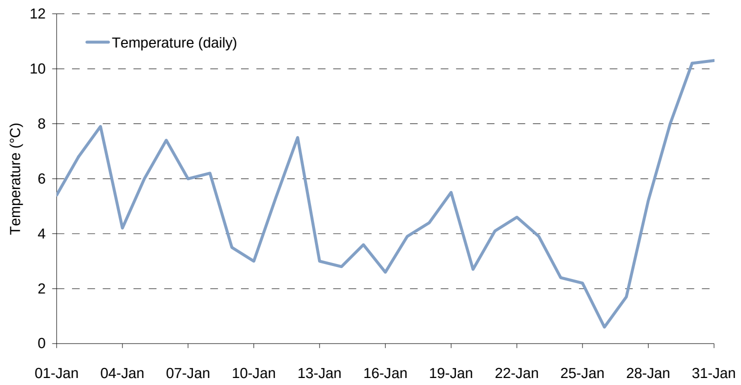
A somewhat similar picture emerges in the Irish market as shown in Figure 12 above, although prices will become more extreme than currently, they will not be as volatile as GB prices. This is due to the market design in the Irish market with the Capacity Payment Mechanism. However, the British market will maintain a strong influence and growing influence on Irish prices.

5. VISUALISING THE 'WIND DRIVEN' MARKET OF 2030

Although the previous chapters have described the statistical distributions of wind output, generation dispatch and market prices, this Chapter describes a particular month in the future. To do this we have asked the models to describe what would happen if the unusual weather in January 2000 repeated itself in 2030. We take this period of time and extrapolate these weather conditions forward as if there is 43GW of wind generation installed in the British market and 8GW in the Irish market.

January 2000 was an interesting month weatherwise: after the mild start welcoming in the New Year, the later part of the month witnessed a large anticyclone start to dominate the weather, giving settled and calm conditions with clear skies and cold frosty nights. The drop in average temperature for the month is shown in Figure 13 below. Under these conditions system demand started to rise.

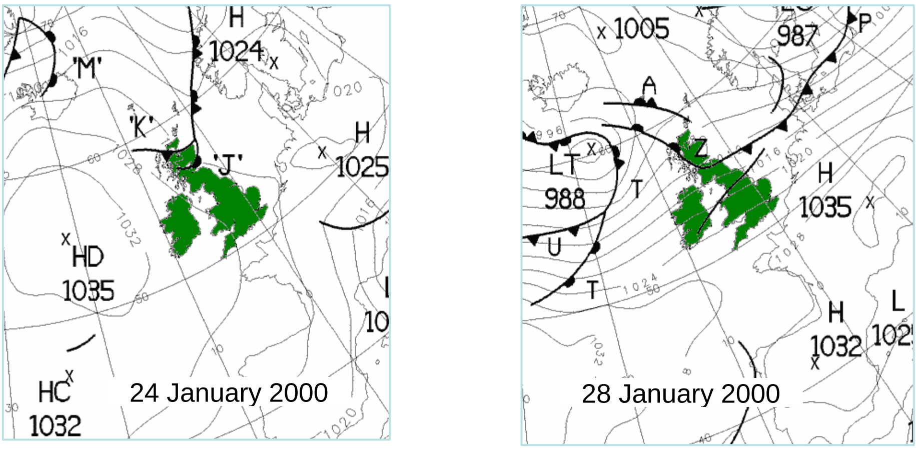
Figure 13 – Temperatures during January 2000



Source: Met Office

The anticyclone prevailed for four days before a large depression swept in to the north of the islands. The weather charts in Figure 14 below show the changes. The depression also brought with it strong south westerly winds, and the wind generation output grew over a space of just a day from very low levels to almost full output.

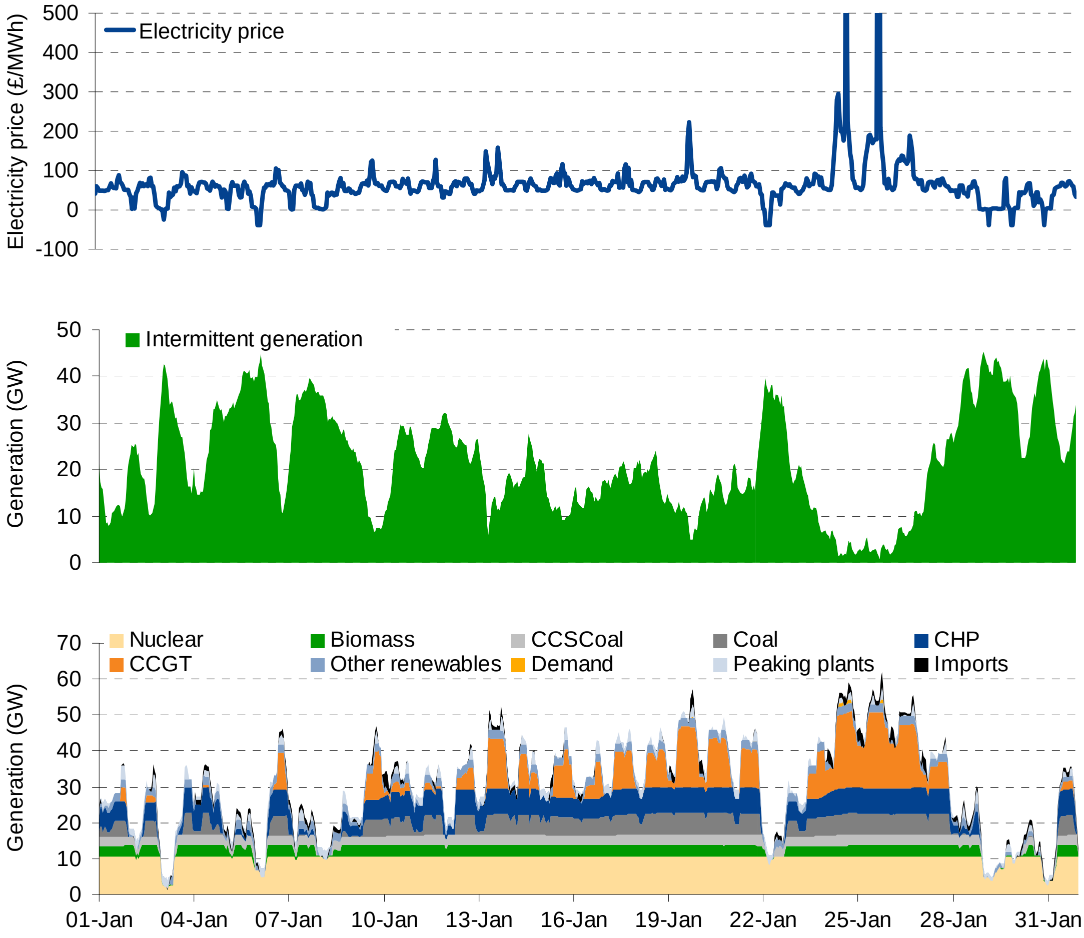
Figure 14 – Weather maps for late January 2000



Source: Wetterzentrale

Figure 15 below illustrates how the British market behaves over the month.

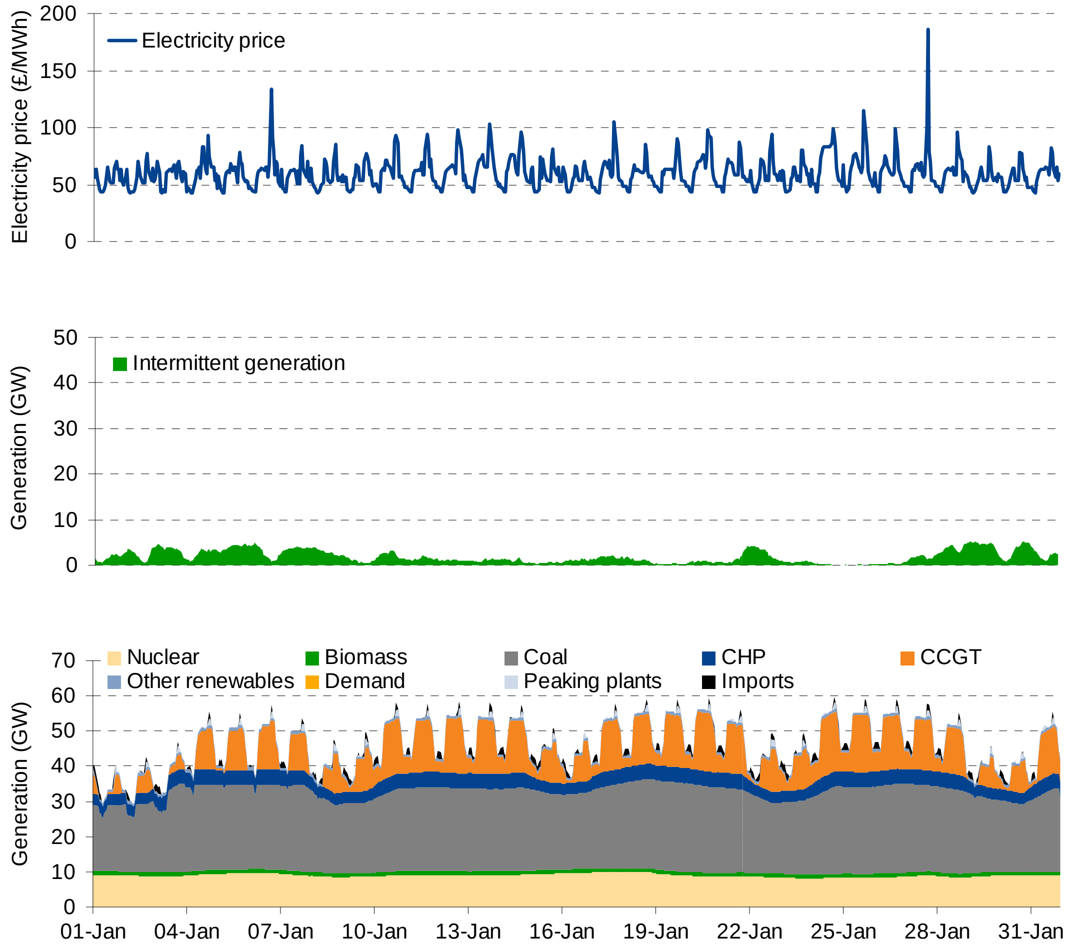
Figure 15 – British market in January 2030 with 2000 weather



The price track shows how the market spikes up and down in the early part of the month, but reaches extraordinarily high levels in the last week when the anticyclone had moved in, but by the end of the month prices were spiking below zero as the wind plant dominates the market.

At the bottom of Figure 15 is the dispatch pattern of the different types of plant, which illustrates the very different running regime – particularly for the CCGTs – where their operation becomes entirely in response to the wind not blowing. The means that the running patterns of all the gas and coal plant on the system are highly irregular and after they start, the time on can range from a few hours to a number of days. Figure 16 below shows for comparison the regular pattern of dispatch today, where the running of plant is dictated by the pattern of system demand.

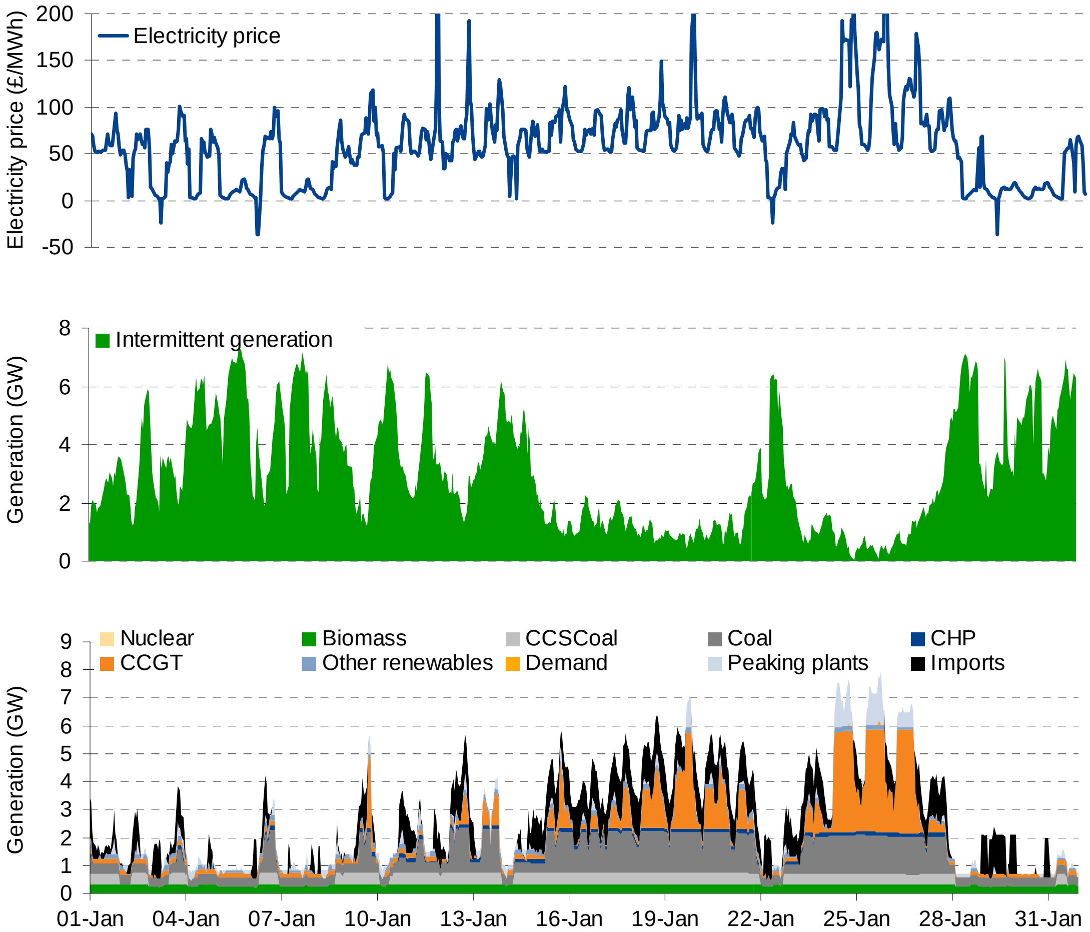
Figure 16 – Typical patterns of prices and plant dispatch in the market today



In the Irish market the impact of the changing weather was even more marked as Figure 17 illustrates. The prices throughout the month show a diurnal pattern in response to the changing demand because of the different rules in the Single Electricity Market.

The changing weather at the end of the month, however, has an even more profound impact on the system – with the wind output rising from almost negligible levels to full output as the weather moves from the anticyclone on 24th to the westerly winds on 28th.

Figure 17 – Irish market in 2030 with weather of January 2000



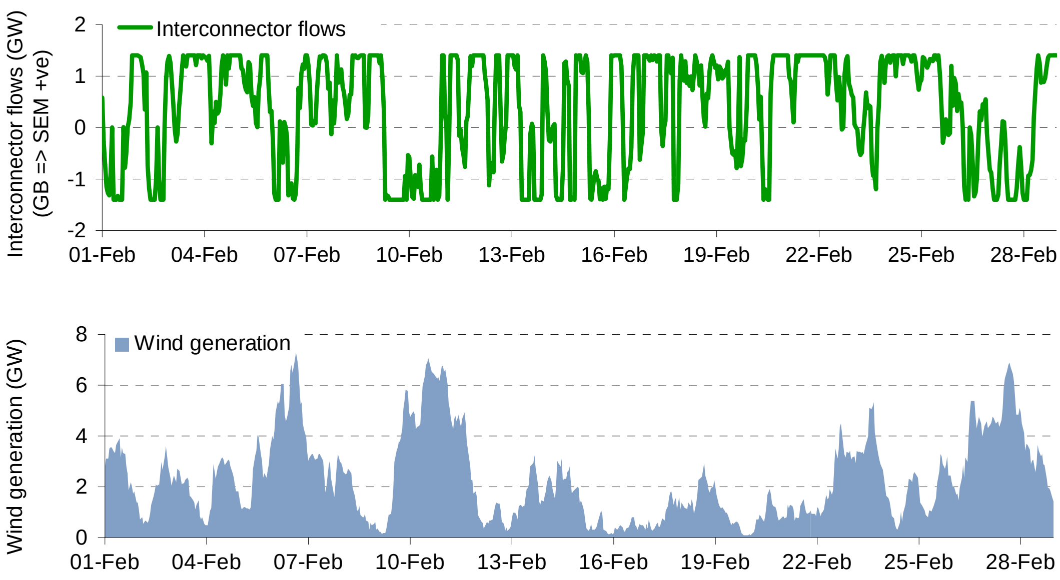
Although we have selected a very specific month to illustrate the behaviour of both marketplaces, events as described here will be a regular feature of the future with large amounts of wind generation, and the price spikes and irregular dispatch patterns will be an enduring feature of the electricity markets.

6. HOW IMPORTANT ARE INTERCONNECTORS?

Many commentators have suggested that the intermittent output of wind generation can be mitigated by greater interconnection between markets, and it was part of this study to provide quantitative answers, especially for the interconnection between the British and Irish markets.

Figure 18 below shows how active the interconnectors will be in response to changing wind output.

Figure 18 – Interconnector flow between the markets and wind generation in the Irish market (2030, weather of 2001)



Our findings underline the almost critical importance to the Irish market of having interconnection to the British market, although the opposite is not true.

However, there are some notes of caution as well: although stronger interconnection does assist the physical management of the system, it has the consequence that British market price spikes also become a feature of the Irish market.

This study would suggest that interconnectors cannot be the 'golden bullet' to solve the challenges of intermittency, although they are extremely important in helping it work.

Our modelling of the interconnection to continental Europe has necessarily been simplified but the tools are in place to extend this study wider. We note though, that in our experience if interconnectors remove price differentials between markets, the commercial case for building them can be challenging.

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7. MANAGING THE GRID WITH HIGH WIND

A significant part of this study was aimed at understanding the way in which the very nature of the wind output required system operators to manage the generating plant differently compared to present in order to maintain current reliability standards.

In particular we were interested in the needs and costs of holding additional plant on the system in readiness to generate within different periods of notice, combined with the wind squeezing out the thermal generators which provide these services.

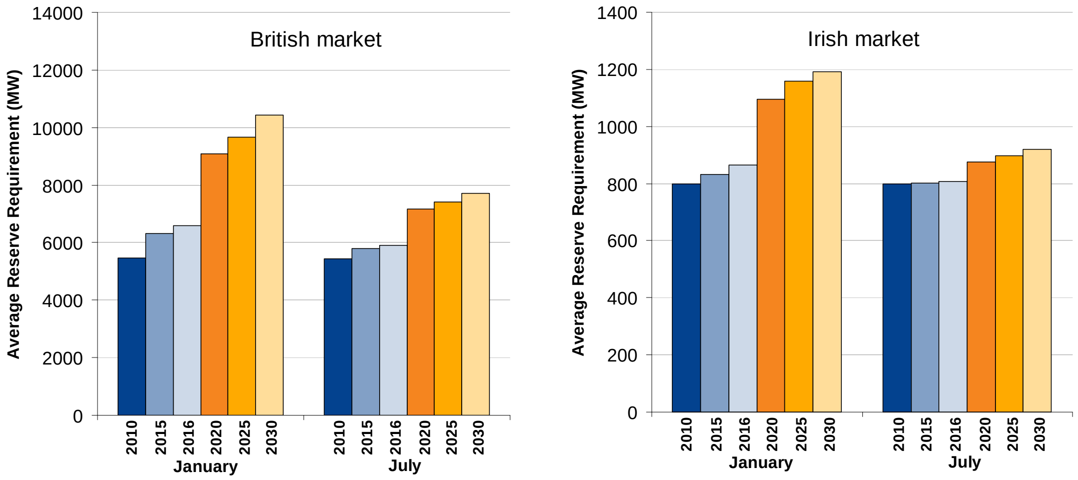
We use the terms *response* and *reserve* for generating plant which is able to come on line within respectively a few seconds and a four-hour window.

The modelling found that *response* requirements did not appear to grow significantly in the British market – although the commissioning of the 1600MW nuclear EPRs in our models had the expected effect of increasing response requirements in the British market because much of the response requirement is governed by fault levels and this type of plant will raise this threshold. In the Irish market there is already a challenge in managing response and we expect a need for appropriate incentives for dispatching off wind.

However, *reserve* requirements will be changed somewhat, and although these seem manageable, both markets will require significant increase in the reserve capacity.

Figure 19 shows the increasing requirements for reserve in the British and Irish markets as a result of increasing wind penetration for January and July. We found that reserve and response to not appear to be critical issues for the British market.

Figure 19 – Base case reserve requirements



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8. MARKET ARRANGEMENTS AND INVESTMENT CLIMATE

A particular aim of this project was to probe the outlook for investors in new generating capacity in both markets.

The earlier part of this report has described in detail the increasingly uncertain and spikey market prices that will become the norm, while another effect of the growing proportion of wind generation is to somewhat reduce average market prices.

Thus the investment drivers for new thermal plant in our Core scenario are not encouraging, especially in later years. New thermal plant will have to operate at low, and highly uncertain loads, and under the current market arrangements the likely returns do not appear good.

In contrast to the Irish market, the British market faces particular challenges for investors. If significant penetration of renewables is achieved along the lines of the Core scenario, power stations which are built now will face a future of not only far lower load factors expected as a greater proportion of the electricity but also dramatically increased uncertainty of revenues than at present.

For example, any generation built before 2016, conceivably to cover closure of existing coal-fired power stations under emissions regulations, would only operate in a ‘stable’ market price regime for a few number of years. Thereafter the revenues will be volatile and uncertain to the point where plant may only operate for a few hours one year, and then some hundreds the next. Generating companies will need to factor this possibility into their investment strategies.

This study gave us a unique opportunity to directly compare the capacity payment system in the Irish market with the energy-only British electricity market. While the Irish market is able to continually incentivise new peaking plant with increasing wind penetration, we are concerned that there is a real challenge in delivering very low load factor plant in the British market.

In our opinion, it is likely that the sort of price ‘spikes’ needed to reward the risks for such plant will stretch the market design to its utmost. The risk of intervention in a market with very high prices for short periods is significant, and has been seen repeatedly in other markets. Equally a market with spikey and volatile prices is one where the risk of operation is greatly increased: it is unlikely to send clear economic signals to new investors.

The scope of this study limited the depth of investigation into remedial actions that might be taken in market design, although it would seem likely that there will be a need to evolve the rules in both markets.

Of particular interest in the Irish market is our finding that there is a consistent difference between the market schedule and the System Operator’s dispatch of plant, because generation is needed for frequency control. The current market rules do not really cater for such services, and there may be a need to specifically reward plant for ‘flexibility’ services.

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9. CONCLUDING REMARKS

Constructing the platforms to understand the statistical and dynamic nature of the likely wind generation needed to decarbonise the UK energy markets has been a major exercise, and one which can now give unparalleled insight. This level of detail has been needed to characterise electricity markets in the future that produce the same level of reliability as today.

Currently electricity markets are really driven by the daily and seasonal changes in demand calling on different types of power station with different costs to be dispatched. However, future markets with large amounts of wind will become completely dominated by the vagaries of the weather – in both the British and Irish electricity markets.

On the face of it, the SEM design has some strong attractions, incentivising OCGTs to provide the dynamic back up to the wind in a market where wind penetration could be much greater.

Equally, the dependence and value to the island of Ireland from the interconnectors between the Irish and British markets stands out.

In contrast, BETTA seems to cope far less well, with several characteristics that will need to be resolved. Many of these problems revolve around the statistical 'tails' when there is either very high or very low wind generation, and it is clear to us that a variety of solutions are open.

Although much more detailed modelling work needs to be carried out to properly model the behaviour of the grid systems in both countries, our concern at the outset of the study that the very dynamics of variable wind output would challenge the system operators has changed to concern about the economic shape of the market.

While this study was deliberately confined to examining the electricity market, there are clear signals that wind intermittency will challenge the gas markets in both islands and these are worthy of similar analysis.

At the outset of this work, we believed that it was vital to inform the debate about the importance of wind in decarbonising the electricity supply by informed, quantitative analysis. This has proved to be a major challenge, but the richness of the information has surprised even the project team, and while the answers we now have are often complex, we believe that any debate on the role of wind can now be properly informed.

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