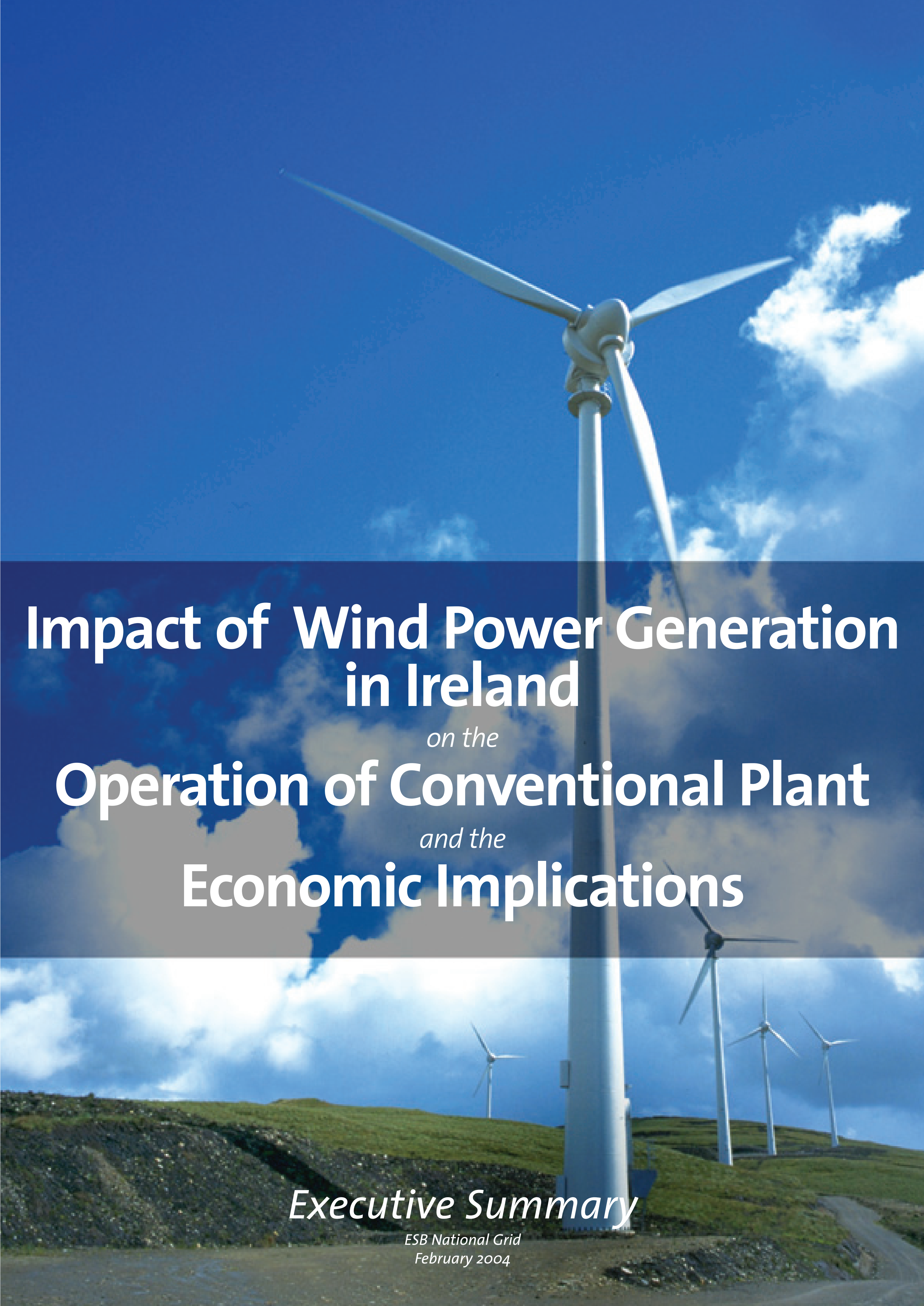


Impact of Wind Power Generation in Ireland

on the

Operation of Conventional Plant

and the

Economic Implications

Executive Summary

ESB National Grid

February 2004

Abstract

An increasing amount of Ireland's electricity needs is likely to be met by Wind Powered Generation. This report quantifies the operational and economic impact of large levels of wind generation on Ireland's generation system[1]. It finds that the potential fuel and emissions savings are tempered by the inherent intermittence of wind. For the scenarios studied total generation costs were found to increase significantly. The implied CO_2 abatement cost from this approach, for large wind penetration levels, was found to be in excess of €120/tonne.

Introduction

The EU has set down indicative targets for the production of electricity from renewable sources for all member countries. The EU targets imply that, on average, across all member states, 22% of Europe's electricity needs should be produced from renewable sources. To meet Ireland's target, 13.2% of the primary electricity needs should come from renewable sources by 2010. ESB National Grid seeks to facilitate this move towards greater renewable energy usage.

Given Ireland's large wind resource, the increasing technical and commercial experience which has been gained within the industry and the level of interest in Wind Powered Generation (WPG), it is clear that more of our electricity needs will be met by WPG in the future.

It has long been the accepted wisdom that the integration of WPG within the Irish system would impact on overall generation operation and costs. While the examination of the implications of high levels of WPG for other countries *(see reference 1)* provides a useful indication of what might happen in Ireland, the implications for the Irish system, given its small size and lack of strong interconnection, could be much more significant. However the exact nature and scale of these impacts have not previously been quantified as detailed modelling of both WPG[2] and conventional plant is required. This report seeks to quantify and explain, for the first time, some of these impacts, subject to a given set of input assumptions.

The report documents studies which simulated Ireland's generation system. The purpose of these studies was to examine the impacts that different levels of WPG will have on operation and economic performance of conventional generation plant. The studies simulate the performance of the power system, at hourly intervals, for each and every hour of the study year.

Analysis based on this time resolution has raised some very significant issues but it is important to understand the context and limits of these studies. They do not examine the interaction of WPG with the transmission network, nor do they deal with the short term (from milliseconds to one hour) impacts on other generation plant. These short term issues would include minute to minute load following, frequency control and reserve provision. Such issues are being actively considered by ESB National Grid and various industry participants in other forums. Other impacts of wind, such as increased fuel diversity, have not been commented on, as this report focuses on issues which may not have been previously understood or fully quantified.

1 *The study has focused on the Republic of Ireland only and All-Island implications are not considered.*
2 *Measured data for both off-shore and diverse on-shore sites has only been available since 2002.*

Analysis and Assumptions

The simulation studies examined the impacts of Wind Powered Generation (WPG) on conventional plant as the installed wind capacity increases.

First, we examined the impact on the Irish power system of increasing the installed wind capacity from 0 to 1,500MW (representing wind energy penetration[3] levels from 0% to 16%), for a year when the peak electricity demand is 5,000MW. Using what is largely the current plant portfolio, this study was designed to reflect conditions which may occur at some stage between 2007 and 2010 as a consequence of using WPG to meet Ireland's renewable energy target.

Secondly, the impacts of very high levels of wind capacity, from 0 to 3,500MW (representing wind energy penetration levels from 0% to 27%), were considered on a larger system having a peak demand of 6,500MW. This study was designed to examine the long term impacts on a system whose thermal portfolio comprises mainly combined and open cycle gas turbine plant and could reasonably reflect a post 2010 situation.

For consistency and brevity we have mostly presented the results for the 5,000MW system in the executive summary. Detailed results for both systems are to be found in the main report.

The input assumptions, outlined below, were chosen to represent a balanced and reasonable view. Alternative assumptions may of course also be modelled.

The WPG model used in these simulation studies assumes diverse wind farm locations, and includes the impact of off-shore wind capacity. This assumption will lessen the adverse impact of WPG on conventional plant, as the aggregate output of such dispersed WPG is less volatile and intermittent than if it was all located within a single region and subject to similar, or more homogeneous, wind conditions.

For the purpose of these studies it was assumed that the output of WPG could be predicted with a high degree of accuracy. This is a somewhat optimistic assumption, which reduces the impact on conventional plant. However, the option of assuming little or no forecasting ability was thought to be unrealistic given the current level of research and development activity in this area.

We have also assumed that the output of WPG is not constrained or controlled by the system operator and is determined by wind conditions alone. This could be considered as the equivalent of 'priority dispatch'. While this is a conservative assumption, as the absence of such control may tend to accentuate the impact of WPG, it does reflect the lack of control which the system operator currently has over WPG.

Findings

The results of the analysis are described under four main headings:

1. **The effect on capacity requirements and utilisation**
2. **The impact on production patterns**
3. **Fuel consumption and emission savings and**
4. **The impact on total generation costs.**

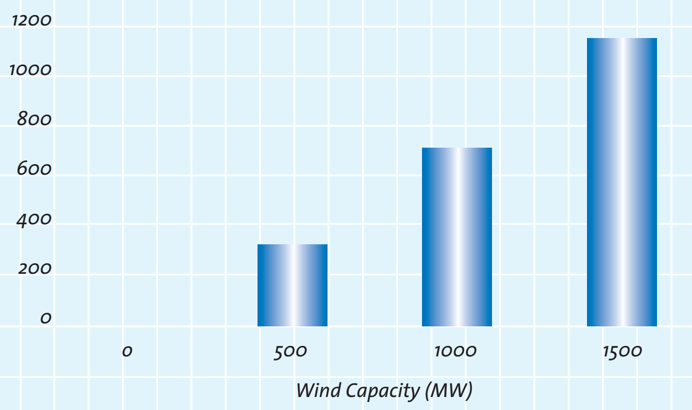
3 Throughout this report the term 'wind energy penetration' refers to the amount of energy provided by WPG as a percentage of the total energy requirement, rather than the fraction of the total installed capacity which WPG represents.

1 The effect on capacity requirements and utilisation

It was found that as WPG increases additional or 'surplus' generation capacity is required if security of supply is to be maintained. This is due to the intermittent nature of wind and the fact that large amounts of WPG can fail simultaneously (when wind speeds move outside the operational range of wind turbines). The 'surplus' capacity is necessary as it acts as a back-up for intermittent WPG.

The 'surplus' is defined in terms of the additional capacity required above and beyond that which would be needed if the generation portfolio was made up of conventional plant alone. Figure A illustrates the surplus plant capacity required to meet the generation adequacy standard[4], above that needed if there was no WPG. It can be seen that as WPG increases to 1,500MW that an additional, or surplus, 1,160MW of plant is required, for generation adequacy reasons.

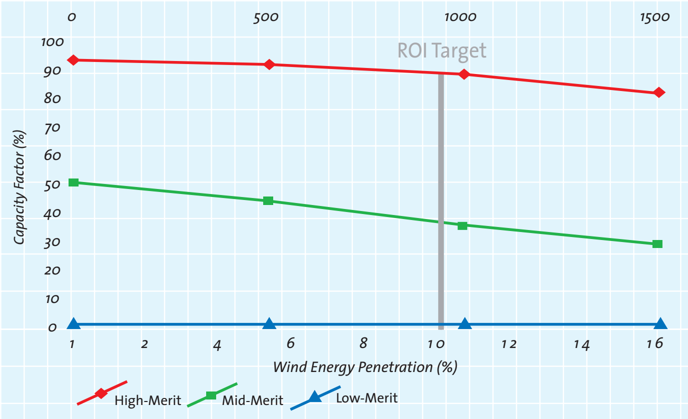
Figure A: Capacity Surplus Required for Adequacy
'5000MW Peak' System



In addition, as electricity generated from wind was always assumed to be taken by the system (ahead of electricity from conventional plant), the utilisation of all conventional plant was found to be curtailed as WPG increased. Reducing market share would normally lead to the uncompetitive capacity being forced out of the market. However, when WPG displaces conventional generation, this capacity reduction is not possible for system security reasons. In fact the opposite happens; WPG requires the system to operate with a capacity 'surplus', which tends to further reduce the utilisation of the conventional plant.

Capacity Factor[5] was used to quantify the reduction in the utilisation of convention plant. Typical results are illustrated in Figure B.

Figure B: Capacity Factors '5000MW Peak' System



In this case it was found that the capacity factor of mid-merit[6] plant, almost halved from 51% to 29.5% as the WPG was increased from 0 to 1,500 MW. High-merit (low-cost/high-efficiency plant) also saw a reduction in output, while low-merit (high-cost/low-efficiency) plant was largely unaffected.

As generators are exposed to substantial fixed costs this reduction in output implies that the price charged per unit of output must increase if generators are to recover their costs.

2 The impact on production patterns

The simulation studies showed that introducing WPG into the generation portfolio changes the operational regime of the conventional generation. While it is intuitively clear that the introduction of an intermittent source of electricity is likely to cause such an effect, it was only through the use of the hourly simulation studies that we were able to quantify the extent of this effect. Figures C and D illustrate how the weekly operation of a combined cycle gas turbine may be affected by the introduction of 1,500MW of wind. Without WPG in the plant portfolio, this unit operates around the clock, in general having to carry out just two load changes per day (reduce output at night and pick up again in the morning). With 1500MW of wind on the system, the unit is forced to come on and off, curtail and vary its output much more frequently.

If high levels of WPG are to be accommodated in the future, existing conventional plant may need to be modified and new plant selected so that it can cope with this type of operation without incurring significant additional costs.

4 Generation adequacy is evaluated in terms of loss of load expectation (LOLE) and is expressed as hours per year. The current generation adequacy standard is 8 hours loss of load per year. LOLE is a statistical measure of the likelihood of failure, and does not quantify the extent to which supply fails to meet demand.

5 The capacity factor of a unit is a measure of the annual energy that the unit produces compared to the maximum possible production level. Therefore for a unit to have a 100% capacity factor it must operate at its full output for every hour of the year, while a 50% capacity factor can be achieved, for example, by either running at half load for every hour of the year or running at full load for only half the hours of the year. capacity factor is therefore a measure of the utilisation of a unit.

6 Mid-merit is defined as medium-cost, load following plant.

Figure C: No Wind Capacity on System CCGT 7 (384MW)

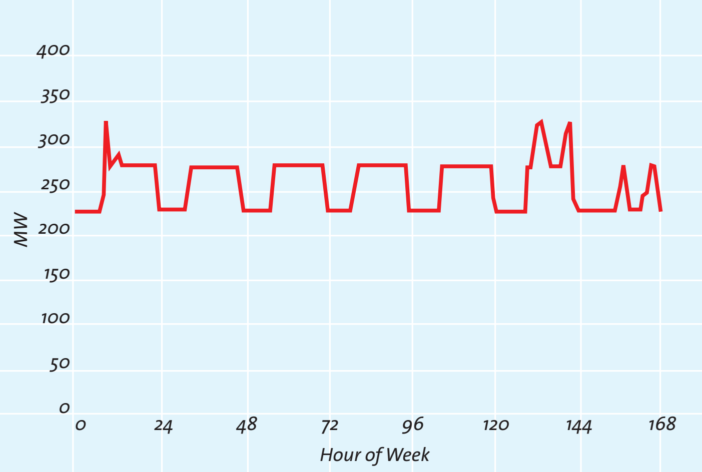
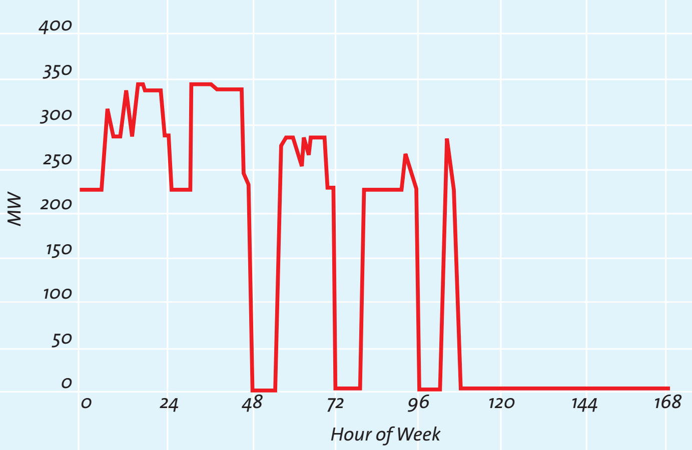


Figure D: 1500MW Wind Capacity on System CCGT 7 (384MW)



In Ireland these changes in the production patterns of conventional plant are accentuated by the fact that, unlike other counties such as Denmark which is strongly interconnected to a highly flexible hydro based generation system in Norway, there is little scope to smooth out the intermittent production pattern of wind.

While these figures give a clear visual indication of how the operating regime of this unit is affected, this impact was also encapsulated by enumerating the impact of WPG on 'start-ups' and the 'average load change per hour'. It was found, for example, that if there was no WPG the average number of start-ups for mid-merit units was 12 per year, or once every 4.3 weeks. With 1500 MW of WPG (equivalent to 15.7% wind energy penetration), the number of start-ups for this same category of plant had risen to 103 per year or once every 3.5 days. Such an operating regime would probably have a significant negative effect on plant reliability.

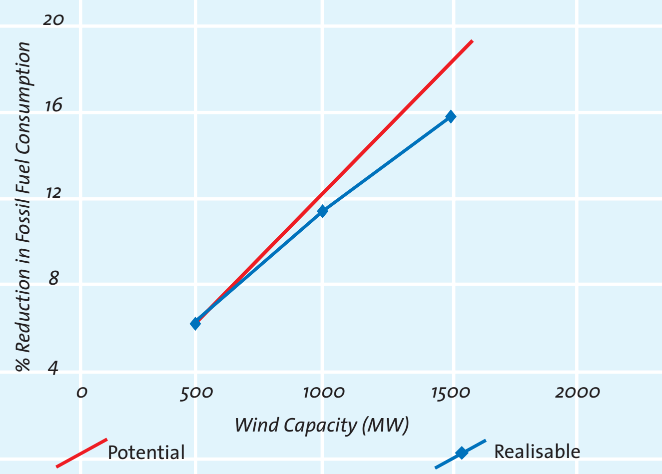
3 Fuel consumption and associated emission savings

The overall quantities of fuel consumed by thermal power plant decreases as more of Ireland's electricity needs are provided by WPG. To accurately quantify the associated fuel consumption, fuel cost and emissions saving, it is not sufficient to estimate the amount of energy which can be obtained from a given capacity of WPG, and to assume that the equivalent amount of fossil fuel derived electricity is displaced. This type of analysis ignores the impact of the increasing number of start-ups and lower capacity factor as WPG increases.

As described previously, the capacity factor for conventional generation is reduced as WPG increases. This lower capacity factor tends to be as a result of conventional units being on line, but operating at lower load levels when WPG is present. The efficiency of thermal plant reduces when it is required to operate at low load levels. Consequently, although there is a reduction in the overall fuel bill when WPG is introduced, this reduction is curtailed by increased inefficiencies as a result of increased startups and lower loading levels.

The analysis presented in this report includes these impacts and therefore offers a more realistic indication of the fuel savings that could be achieved by increasing WPG. Figure E illustrates the impacts on a system with a peak demand of 5,000MW. It can be seen that 500MW of wind reduces the requirement for fossil fuel by 6.1% which represents a fuel cost saving of €51m. This result occurs at relatively low levels of WPG penetration as the operation of conventional plant is not greatly changed.

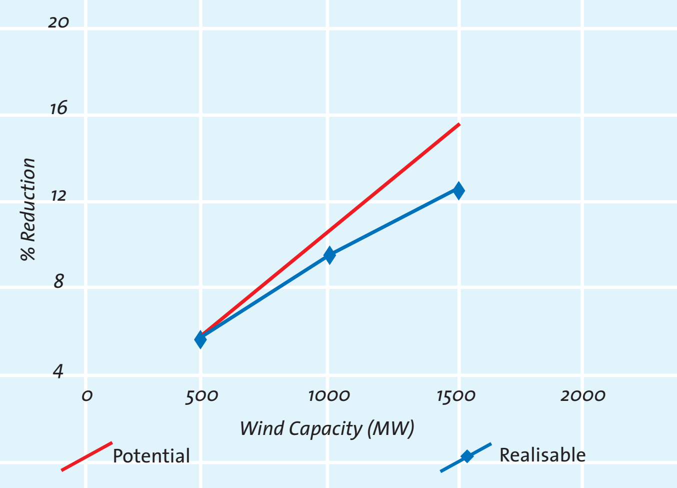
Figure E: Impact of WPG Operational Characteristics on Potential Reduction in Fuel Usage



If there was a fuel saving of 6.1% associated with the introduction of 500MW of WPG, it might have been expected that the 'potential' fuel saving would have been 3 times this, or 18.3%, for 1,500MW. However, as WPG increases to 1,500MW it was found that the corresponding reduction in fossil fuel requirements is only 15.7%, corresponding to a fuel cost saving of €130m rather than the €153m which may have been expected. This is a manifestation of the growing inefficiency of thermal generation as it is required to act as counter-balance for WPG.

It was also found that there was a reduction in emissions due to the inclusion of WPG in the generation portfolio. This occurs due to the resultant decline in output from conventional plant. However, this reduction is tempered by the fact that even though the conventional plant is producing less electricity, the efficiency of the conversion process has been adversely affected by the presence of an intermittent source within the portfolio.

Figure F: Reduction (%) in CO_2 Emissions 'Peak' 5000MW System



As Figure F illustrates, the realisable savings in emissions falls short of that which would be expected on a pure energy displacement basis. As wind penetration increases, the effectiveness of adding wind to reduce emissions diminishes.

It can be seen that 500 MW of wind reduces the amount of CO_2 emitted by 5.4%.

If there was an emissions saving of 5.4% associated with the introduction of 500MW of WPG, it might have been expected that the 'potential' fuel saving would have been 3 times this, or 16.2%, for 1,500MW. However as WPG increases to 1500 MW it was found that the corresponding reduction in fossil fuel requirements is only 12.9%. This quantifies the reducing effectiveness of using WPG to curtail CO_2 emissions.

4 Impact on total generation costs (6,500MW scenario)

The total cost[7] of meeting customer electricity demand was found to increase as the penetration of wind generation increased. This is largely due to the retention or installation of surplus conventional capacity, for system security reasons, and the operation of all installed conventional capacity in a sub-optimal manner.

We estimate that for a system[8] with a peak of 6,500MW, and a generation portfolio comprising of combined and open cycle gas turbines, and no WPG, that the total annual generation costs would be €1.28bn. When WPG is increased to 1,500MW the total generation costs increases by €196m per annum to €1.48bn.

For a system with a peak demand of 6,500 MW, 1500 MW of WPG represents an energy penetration level of 11.7%. The EU target for Ireland, from all renewable sources, is

7 This includes the fixed and variable costs for both conventional plant and WPG.
8 This analysis was not carried out for the 5000 MW system as full generation costs of the current plant portfolio are not available to ESB National Grid.

13.2%. Therefore it can be estimated that, in the long term, using WPG to comply with the EU target will increase electricity generation costs by 15% (€196m as a percentage of €1.28bn).

If WPG is increased further to 2,500MW, Ireland would be in a position to achieve the average EU target for electricity production from renewable sources of 22%.

However this would increase the total generation cost by €310m representing an increase in total generation costs over the no wind case of 24%.

It should be noted that it is the total generation costs rather than the delivered electricity price which is referred to here. While total generation costs are a major component of the electricity price there are other components, including use of network charges, losses and system support costs[9]. Consequently, the percent total generation cost increases quoted give an indication, rather than the absolute value, for the price increase which the customer may see as a result of WPG. Such increases will vary by customer category and are likely to be most noticeable for large industrial customers. The reason for this is that total generation costs represent a greater percentage of the end price paid by this customer category because there is no charge for the use of the low voltage network.

The reduction in CO_2 emissions for this 6,500MW system with 1,500MW of WPG (representing wind energy penetration levels of 11.7%) over the case with no wind was found to be 1.42 million tonnes. However the total generation cost increased by €196m implying a cost per tonne, of CO_2 reduction, of €138.

One of the key economic considerations for Ireland is the cost of meeting carbon emission reduction targets set by the Government in response to EU and Kyoto protocol obligations. Measures which encourage a reduction in consumption (carbon taxes[10]), substitution with non or low carbon technologies (renewables), purchase of emissions quotas (economic reduction of carbon emissions elsewhere), all constitute feasible policy options. In choosing between these options, it is important that a minimum cost objective be adopted in the context of maintaining Ireland's economic competitiveness. The carbon reduction costs implicit in the wind penetration levels considered in this study appear high in comparison, for example, to current estimates for the trading price of carbon allocations.

Conclusion

The purpose of this report is to inform the debate on renewable energy in general, and more specifically to quantify some of the technical and economic consequences of using high levels of wind powered generation to meet the requirement to reduce our dependency on fossil fuels and curtail emissions.

Based on a set of plausible assumptions, it was found that producing more electricity from wind will have an ever increasing impact on the performance of other generation plant on the system. These impacts tend to be adverse in nature, reducing the efficiency and increasing the operational demands on conventional plant. It was also found that the law of diminishing returns applies. The capacity benefit and emissions savings decline as the penetration of wind increases.

The cost of CO_2 abatement arising from using large levels of wind energy penetration appears high relative to other alternatives. It is possible that improved awareness of the adverse, as well as the positive, impacts of WPG will help to increase the benefit and reduce the costs associated with increased penetration levels.

While this report illuminates part of the picture it should be understood that wind generation will other have impacts, both positive and negative, outside the scope of this work.

The main report can be downloaded from: ***www.eirgrid.com***

Reference:

W. Leonhard, K. Muller, CIGRE Autumn 2002. Balancing Fluctuating Wind Energy with Fossil Power Stations.

"Results show that even at this low penetration of wind energy, the infeed causes a hidden increase in the specific fuel consumption in remote fossil generating stations, they are now producing less electrical energy but with higher fuel consumption and CO_2 emissions per KWh".

9 This report does not quantify the impact, favourable or otherwise, of WPG on these other components of the electricity price.

10 The Department of Finance consultation paper on carbon taxes, February 2004, suggests a tax which varies from 17.25 to 103.5 f\t$CO_2$ depending on taxation levels and fuel type.

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Lwr Fitzwilliam Street, Dublin 1. Phone 01 702 6749