Study into the impacts of increased levels of wind penetration on the Irish electricity systems: First Interim Report

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For The Commission for Energy Regulation and OFREG

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1 INTRODUCTION

1.1 Background

Wind energy deployment is relatively new in Ireland, particularly when compared to other E.U. Member States such as Germany or Denmark. The first commercial wind farm of 6.45 MW installed capacity was commissioned in 1992. Development remains relatively modest, with 29 wind farms currently in operation. These represent a combined installed capacity of 161 MW, compared with a total generating capacity on the island of over 6,500 MW. Wind energy currently contributes about 1.5% of Ireland's electricity demand and 2.4% of generating capacity.

It is anticipated that a significant accelerated growth in deployment will occur in the short term as evidenced by ambitious targets and the amount of activity in the market in on-shore and off-shore wind energy. The impacts of this growth on the electricity network has prompted the study.

In the **Republic of Ireland**, the *Green Paper on Sustainable Energy* (in 1999) set a target for renewable energy of an additional 500 MW installed capacity by 2005, most of which is anticipated to come from on-shore wind energy. The EU *Directive on the Promotion of Electricity from Renewable Energy* (2001) detailed indicative targets for each of the Member States for 2010. In the Republic of Ireland's case, the target for electricity produced by renewable energy in 2010 is 13.2% of gross electricity consumption. This would require an additional target of approx 400 MW from renewable energy for the period 2005 – 2010. If this all is provided by additional wind farms, then wind generated electricity will contribute **10.4% of Ireland's electricity needs** by 2010. No national target has yet been announced for this period, although the National Climate Change Strategy states that *'significant further expansion will be required…..having regard, inter alia to targets at EU level.'*.

In February 2002 the Department of Public Enterprise published details of wind farms with a combined installed capacity of 354 MW that had secured Power Purchase Agreements under the AER V scheme. These projects will mark the first significant step in reaching the 500 MW target by 2005.

Activity in the market place indicates plans for wind farms with a cumulative capacity of **approximately 2,000 MW on-shore and a further 2,000 MW off-shore**. By November 2001, wind farms with a combined installed capacity of 363 MW had secured planning permission and a further 240 MW were within the planning process awaiting a decision. It is estimated that additional applications for planning permission for wind farms will be submitted before the end of 2002 for a further 1,500 MW. Regarding off-shore wind energy, foreshore licenses have been issued for 7 sites, mostly on the East Coast. To date one foreshore lease has been issued for a proposed 520 MW wind farm. Based on information available from the developers, the combined capacity may be as high as 2,000 MW.

In **Northern Ireland**, the Committee for Enterprise Trade and Investment Report on the Energy Inquiry recommends an implementation plan be established to meet the target of 15% of electricity demand from renewable energy by 2010. It further recommends the establishment of a Renewable Energy Obligation, as exists in Great Britain. The UK Crown's Estate has initiated a competition to bid for the option to develop a 150 – 250 MW wind farm off the coast of Portrush, County Derry.

An assessment has been made of the likely expansion of wind generation on the island of Ireland, for the purposes of subsequent elements of this work, and this is summarised in Section 3.4.

1.2 This study

The Commission for Energy Regulation (CER) in the Republic of Ireland, in co-operation with the Office for the Regulation of Electricity and Gas (OFREG) in Northern Ireland, has commissioned Garrad Hassan (GH) to undertake this study of the effects of increased levels of wind penetration on the electricity system of the island of Ireland. The Terms of Reference are summarised in Appendix 1.

The work is being led by GH, with ESBI and the Sustainable Energy Research Group of University College Cork as subcontractors.

The clients' requirements are best summarised by the key questions listed in the original Request for Tenders:

1. ***What is the feasible level of wind penetration, which can be safely and securely accommodated given the existing RoI and NI transmission systems and plans for their reinforcement?***
2. ***How is this level determined at the moment by the respective transmission system operators?***
3. ***What are the potential impacts of increased wind generation on system reliability and power quality?***
4. ***What are the economic costs and benefits of accommodating increased wind generation?***
5. ***What are the potential impacts of increased wind generation, in terms of both price and quality of supply, on final customers?***
6. ***Are there any other factors, which will potentially impact on the ability of the system to handle increased amounts of wind generation?***

Progress on each of these questions is summarised at the end of Section 2.

This document is the first interim report on this work. It covers Tasks 1 and 2 of the agreed programme of work. It has been produced to provide an opportunity for interested parties to understand the intended work and methodology, and to comment on the background established in Tasks 1 and 2.

As this is an interim report, principally on the work done for Tasks 1 and 2, no overall Executive Summary is included. The conclusions to date are summarised at the end of Sections 2 and 3.

GH will be pleased to receive comments on this document from interested parties. Comments should be sent to Paul Gardner gardner@glasgow.garradhassan.co.uk (Please note that GH cannot undertake to reply to comments individually).

2 TASK 1: ESTABLISHING THE BACKGROUND

2.1 Previous experience

This section describes reported operational experience and research findings.

For simplicity, it is useful to define some terms. The following definitions are to be used in this study, and may vary slightly from similar definitions used elsewhere.

- **Installed capacity penetration**: this is the installed wind generation capacity (in MW) connected to an electrical system, normalised by the capacity of all generation installed on that system.
- **Operating capacity penetration**: this is the wind generation capacity (in MW) actually operating at a given time, normalised by the system demand at that time.
- **Output penetration**: this is the output of the wind generation (in MW) at a given time, normalised by the system demand at that time.
- **Energy penetration**: this is the electricity produced by the wind generation, normalised by the gross electricity consumption in the electrical system, usually on an annual basis.

2.1.1 Wind power and the experience of electrical systems to date

The development of wind power in the last 25 years is a story of progress from small-scale experimental machines, used to prove the concept, to large-scale wind farms commissioned as entirely commercial ventures. Power systems across the globe have accommodated wind power, initially on distribution systems and latterly, with the advent of large-scale wind farms, on transmission systems. This process of accommodation, which has continually given rise to technical and economic challenges that power system engineers and project developers have had to overcome, continues today with the creation of off-shore wind farms.

The growth of wind power on the island of Ireland has, to date, been relatively modest, with 29 wind farms with approximately 161MW in operation. Of this only 15 MW is connected to the transmission system, with the overall production capacity on the island being in excess of 6500MW. This represents an installed capacity penetration of 2.4 %. Given the abundance of the wind resource available in Ireland, the decreasing costs of the technology and 'green' dividend associated with such energy, this low growth situation is unlikely to persist.

If the renewable energy strategy being promulgated by both jurisdictions is successful the installed capacity penetration is predicted to rise to approximately 16% by 2010, as shown in Table 2.1. This table is based on Government targets in both jurisdictions which are expected to result in wind producing approximately 10 % of electricity production in 2010. The required wind capacity is then calculated assuming an average capacity factor of 0.35. It should be noted that the total generation capacity forecasts used in the table are forecasts based on 'business as usual', i.e. that the addition of wind on to the system does not decrease the conventional generation capacity. At high wind penetrations, this assumption may not hold true. In this case, the capacity penetrations shown in the table would increase.

Item	Island of Ireland (current)	Republic of Ireland (2010)	Northern Ireland (2010)	Island of Ireland (2010)	Eltra system, Denmark (current)
Wind energy penetration	1.5 %	10 %	10 %	10 %	16.2 %
Total conventional generation capacity [MW]	6,500	5,067	2,012	7,079	4,724
Total wind capacity [MW]	162	1,042	351	1,393	1,932
Total generation capacity, including wind [MW]	6,662	6,109	2,363	8,472	6,656
Installed wind capacity penetration	2.4 %	17.1 %	14.9 %	16.4 %	29.0 %

Table 2.1: Comparison of forecast wind penetration in Ireland with Eltra system

One power system that has coped with significant penetration of wind power is the Danish system. For comparison, the data for Eltra, the Transmission System Operator (TSO) for the western part of Denmark, are also shown in Table 2.1. It can be seen that the forecast for Ireland in 2010 is, on paper, less onerous than the current situation in the Eltra area. However, it is important to note that the Danish system differs from the Irish system in having significantly more interconnections to neighbouring systems. This is expected to have a major effect, and will be considered in subsequent tasks.

The historical growth in wind power in western Denmark is shown graphically in figure 2.1. This exponential growth in wind power is challenging for system operators and planners. The rates of growth are similar to those expected in Ireland.

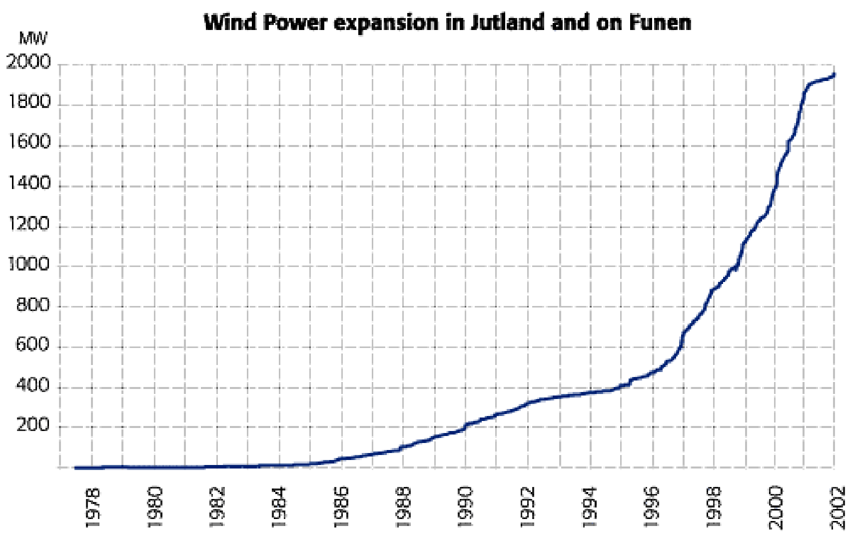

Figure 2.1: Wind power expansion in Jutland and on Funen

Whilst not all systems have, or are capable of having, the same degree of penetration as the Danish system it is instructive to examine the challenges faced by systems such as Denmark. Broadly they can be broken down into a number of different categories:

2.1.1.1 Ensuring generation adequacy

Power systems are designed to have sufficient production capacity (generation) to meet the variable (but highly predictable) load requirements of customers. Traditionally probabilistic measures have been used to assess the requirement for additional generation resource to ensure a reliable power system. One such measure in common use is Loss of Load Expectation (LOLE). This evaluates the risk of insufficient capacity in terms of the expected time per year that a peak load will exceed the available generation capacity.

Wind presents several challenges when modelled as a production resource. It is variable in amplitude, over a wide range of timescales. However its statistical properties are understood, and it is predictable to some extent on some timescales. As wind penetration grows it is imperative that appropriate modelling techniques for wind energy are utilised so that the generation adequacy of the power system as a whole does not degrade. A greater degree of wind penetration does not necessarily equate to a degradation of generation adequacy. Wind power cannot (even in a resource rich location such as Ireland) replace conventional power MW for MW. However getting the correct balance will require refined and constantly improved modelling of wind energy on the island, over all timeframes.

At present wind energy is taken into account when modelling generation adequacy.

<u>Over production</u>
The most serious operational challenge that has faced the Danish power system is, ironically, not to ensure that there will be enough wind energy at any point in time to meet the load, but rather what to do when there is too much energy from wind and local CHP plant. These essentially non-dispatchable sources of energy have, on occasion, at times of low load and/or high wind, produced a significant surplus. This has produced operational and economic problems for the power system, because wind generation in Denmark is in effect unconstrained. These problems could be limited by policies which allowed the system operator to constrain wind generation at critical periods.

2.1.1.2 The planning of the power system

Accommodating the expansion of wind power whilst ensuring the orderly and reliable development of the power system has not been faced before by most system operators and is not straightforward. Traditionally models of the power system are developed and a number of possible future scenarios (different load growth rates, new generation developments, system interconnection) are tested against a set of transmission planning criteria. Typically this analysis is carried out for 5, 7 or 10 years into the future. When the analyses indicate that the power system operation will infringe the criteria in a particular year, then system reinforcements are suggested which will bring the power system back to standard.

This orderly process of power system development, which has provided reliable electricity supply, faces a number of challenges as the penetration of wind power increases in a system. Wind power tends to:

- Have a low capacity factor, which results in relatively high capital investment in the power system in relation to the energy production;
- Have less predictable and controllable power production than thermal generation;
- Be capable of construction in much shorter timescales than is usual for transmission reinforcements.

In addition, wind farms constructed to date tend to:

- Locate in weak areas of the power system;
- Have less developed models of generator characteristics than conventional generation;
- Provide less support during system disturbances than conventional generation.

These are factors that challenge the system planning/modelling process. However, some of these factors can be and are being addressed by turbine manufacturers and wind farm developers, particularly for larger wind farms. Eltra, in its latest system plan, has stated its intention to modify its planning criteria/methodology to better address the unique features of wind power.

It is also interesting to note, given the Danish experience of major wind power penetration, the strategy for coping that they are implementing is an increase in the capacity of the existing interconnection with the NORDEL system (specifically to Norway). This has the advantage of improving generation adequacy and giving a greater ability to cope with the aforementioned oversupply difficulties. This strategy may not be feasible or technically satisfactory in the case of the island of Ireland. The existing Moyle interconnection with Scotland, while technically capable of 500 MW, is in effect limited to approximately 450 MW because of restrictions elsewhere. The available trading capacity (ATC) has been set at 300 MW to September 2002, and 400 MW to March 2003 [1]. There are further technical restrictions between the Moyle landfall and the main ESB system, and the ATC for transfers north/south has been set at 170 MW. Further expansion or new interconnections are under investigation, and would be major investments. Furthermore Scotland is seeking a significant expansion in its wind power resource, potentially eliminating some of the temporal diversity that would be exploited by increasing the capacity of the existing interconnection.

2.1.1.3 Operation of the power system – Power and energy balance

The day to day, moment to moment operation of the power system in developed economies with a high level of wind power penetration has proven a challenging experience. The operators must seek to balance production with generation without breaching system constraints, maintain the quality of supply to consumers, while operating the system economically. Additional variability introduced by wind, on timescales of seconds to hours, makes these tasks more difficult. From a theoretical point of view, the variability introduced by wind should not be significant until the penetration is sufficient for the variations to be similar in scale to the variability introduced by the random behaviour of electricity consumers. On short timescales of seconds or minutes, wind forecasting error over a large geographical area is expected to be small compared to load forecasts, except during extreme events such as storm fronts, on which much forecasting effort is being expended. On timescales of days, forecasts of wind production can be wrong by 100%, which is clearly much greater than the forecasting error for demand.

In Denmark where the bulk of the wind resource is of an uncontrolled nature, connected to the distribution system and is in no sense 'dispatchable' or controllable the Danish operators have found that good wind forecasting is critical to successful operation. The electricity system on the island of Ireland has some similarities with the Danish systems, but also some differences:

- the Irish system is less interconnected, in fact almost completely isolated from other systems;
- the Irish system does not have the additional problem of 'must-run' heat-led CHP plant.

These issues will be studied in subsequent tasks.

As well as the problem of balancing such a system from an energy perspective, several other operational problems have emerged.

Generators deliver a range of other products that are necessary for the operation of a power system. This broad class of essential services that operators use to control the power system are named ancillary services. They range from operating reserve and reactive power through short-circuit current contribution and black start capability. The inability of wind generators to produce these ancillary services in a dispatchable, controllable way has been of serious concern to operators in Denmark. If centrally-dispatched thermal plant, which can produce such services, is displaced by wind power in an unchecked fashion, there will be difficulties in operating the power system. These issues are likely to emerge earlier in the Irish systems, as there is much less interconnection with neighbouring systems.

2.1.1.4 Operation of the power system - Transmission

In addition to the considerations of energy and power balance, high levels of wind power penetration also have implications for the planning & operation of the transmission system. Of these, the most important is introduced by the variability of wind power output, and the need to be able to compensate for this by the provision of ancillary services (in the form of extra regulating or operating reserve) as outlined above. Conceptually it is attractive for any plant providing new ancillary services to be connected to the transmission system very close to large concentrations of wind power,and for some services there may also be technical advantages. However, in general, this is unlikely to be optimum for ancillary services such as regulating and operating reserve. In most cases existing sources of these services (pumped storage, open cycle gas turbines etc.) will be connected to the transmission system in a different part of the country, and the optimum location of new plant installed to provide these services may also be remote from the wind farms.

The output from a wind farm will vary with wind speed. If these variations are large and rapid there will be corresponding changes in the magnitudes and directions of power flows from the wind farm itself, and from the generators providing regulating and operating reserve services elsewhere on the system. Unless these are countered very quickly, the voltages on the system also will vary, and, if the variations are large enough, limits may be infringed.

Voltages on the transmission system are controlled through a combination of generator excitation systems, transformer tap-changers, static reactive devices and increasingly Flexible Alternating Current Transmission System devices (FACTS). FACTs devices combine modern power electronics control techniques with elements such as capacitors, inductors and transformers. In the present context the most important FACTs device is a Static Var Compensator (SVC). Variations due to wind farms are likely to be too rapid for transformer tap-changers, and too large for the generator excitation systems of many generators. Operators will have to rely to an increasing extent on FACTS devices. These devices are well proven, but highly expensive.

The response of the system to faults must also be considered. The issues that are particular to wind generation are:

- To provide a robust system, connections to wind farms, particularly large wind farms, should provide the same level of redundancy as connections to conventional generation. This will be more expensive than connections for conventional generation, partly because wind generation is often located remote from load centres, and partly because the low capacity factor of wind generation means the energy produced per MW of transmission capacity is low.
- It could be significantly more expensive to provide sophisticated protection systems for wind farms distributed over an area than for conventional generation of equivalent capacity.
- Conventional generation largely uses synchronous generators, which are able to continue to operate during ('ride-through') severe voltage transients produced by transmission system faults. This capacity has not yet been demonstrated for the generator/drive types

currently favoured for wind generators, and there are technical reasons for believing that it will be difficult to mimic the satisfactory behaviour of synchronous generators. If large amounts of wind generation is tripped by a fault on the system, the negative effects of that fault could be greatly magnified.
- Some of the generator/drive systems currently used in wind turbines may, during a fault, consume large amounts of reactive power from the system. This may make recovery from the fault much harder.

2.1.2 Wind turbines, wind farms and wind energy power plants

2.1.2.1 New developments

Two watershed developments in wind turbine technology are emerging:
- Construction of very large wind farms with rated outputs measured in hundreds of MW, and,
- Incorporation of increasingly sophisticated power electronic and computerised controls into wind turbines

In addition to the above developments in wind turbine technology recent research carried out in Ireland and abroad seems likely to lead to significant improvements in the accuracy of very short term forecasts of wind patterns.

The first of the new developments in wind turbine technology can be expected to increase the difficulties to be faced by operators; the second, combined with improvements in forecasting of wind patterns, appears to offer a possible way to address these difficulties.

2.1.2.2 Impact of very large wind farms

A very large wind farm with a rated output of several hundred MW, to be connected to the transmission system at a single point, will have a more significant impact on the system power and energy balance than the same total output dispersed in small wind farms over a large area. This is because, at any one time, the weather will very rarely be uniform over a large tract of country.

This means that a change in wind speed at one place would affect only that portion of the total rated output that was installed there. However, if the entire capacity were to be concentrated in that one place, the total output would be affected, and the impact on the power system would be correspondingly greater.

A transmission system operator therefore could reasonably expect that the combined output of the wind farms which were widely dispersed across the country would rarely fall to zero, so reliance could be placed on the availability of some proportion of their combined rated capacity (but see Section 2.2.2 for the effect of anticyclonic weather in winter). Of course this dispersal of generation may require significant transmission system reinforcement. However, if the same total capacity were to be concentrated at one point, a much lesser reliance could be placed. This issue is of major importance for this study and will be considered in Tasks 4 and 5.

2.1.2.3 Impact of sophisticated controls

The development of sophisticated controls for wind turbines, combined with expected improvements in short-term forecasting of wind patterns, is expected to produce considerable improvements in the predictability and controllability of the output of large wind farms.

If this is realised, it will significantly mitigate the impact of very large wind farms, and thus improve their acceptability to TSOs.

The anticipated developments in control functions are closely related to the expectations of TSOs as described in the draft grid code revisions, because both are facets of the same issue. The control improvements anticipated include, in increasing order of technical difficulty:

- the ability to limit wind farm output to an arbitrary level, probably under direct control of the TSO;
- the ability to limit wind farm rate-of-change of output ('ramp rate'), both up and down, to an arbitrary level, again probably under the control of the TSO;
- the ability to automatically control wind farm output downwards (and possibly upwards, transiently) to provide some form of frequency response;
- the ability to control wind farm reactive power (import and export), in various control modes including mimicking a synchronous machine with automatic voltage regulation;
- the ability to control real and reactive power on transient and sub-transient timescales sufficiently to be able to 'ride-through' specified faults on the TSO system, either by remaining synchronised or by rapidly disconnecting and then reconnecting within a specified interval.

To put these functions in context, it should be realised that currently the vast majority of control functions in a wind farm reside in the turbine controllers: the wind farm 'control' system is in fact more of a data recording and analysis system, with only limited control functions at a slow (~1 minute) update rate. It is extremely unusual for any direct control function to be given to the system operator. Therefore it appears inevitable that the wind farm controllers will increase in functionality, with better communications with the turbines and with external agents (principally the system operators).

The very rapid control functions required for responding to faults on the TSO system will need to be handled by local controllers in the wind turbines, and in any ancillary equipment such as static VAR compensators. Therefore it is expected that improvements will be required in the following elements of the wind turbines:

- supervisory controllers
- pitch systems and pitch controllers
- power converters.

2.1.2.4 Wind Energy Power Plants (WEPPs)

TSOs have obligations to operate the systems reliably, safely, and economically, and to treat system users equally. Given the concerns expressed by system operators internationally with significant levels of wind penetration on power systems, it is no surprise that TSOs are devising new strategies for accommodating these new developments. ESB National Grid is of the opinion that it is not the TSO's responsibility to develop such strategies: instead the responsibility should be taken by the wind industry. In practice, however, ESB National Grid is proposing Grid Code modifications which will address these issues, as noted below.

An important part of this is the introduction of the concept of Wind Energy Power Plants (WEPPs).

In simple terms a WEPP is a wind farm that behaves exactly like a conventional generator except for the variability of the fuel source. The ideal wind energy power plant in addition to providing energy must:

- Deliver a range of ancillary services to the power system,

- Produce energy in a controlled fashion, ramping up and down in a manner similar to the performance of conventional generation,
- Contribute positively to system stability, fault recovery, power quality and the performance of the protection system.

TSOs in Ireland, Scotland and Denmark have all produced documents (mostly still in draft and confidential form) that outline the requirements for the performance of wind farms connected at the transmission voltages, and perhaps also in diluted form for smaller wind farms or even single turbines connected to distribution systems. The concept of a WEPP is part of these documents. Clearly the TSOs wish to adapt their existing policies and procedures to incorporate wind, while maintaining a reliable system. This strategy by TSO's will be successful provided:

- it is technically possible to deliver on the requirements;
- it is possible to do so at an acceptable cost;
- there is a clear understanding of the strategy and its requirements among project developers & wind turbine manufacturers;
- the timescales for introduction of the requirements are not too rapid to allow the necessary design and development work to take place;
- and the approaches of the TSOs are not radically different, so there is only one set of targets to meet.

An analysis of these documents produces the following conclusions:

- some of the proposed requirements are likely to be met at very little cost (virtually all design costs, or communications and control hardware costs);
- some of the proposed requirements (for example, the ability to 'ride-through' faults on the system) could imply significant cost;
- some of the proposed requirements will tend to favour some wind turbine concepts and technologies over others.

GH considers that many of the improved control functions currently being discussed within the industry, and anticipated in the draft grid code revisions, are not likely to require long development periods. The timescale is more likely to be governed by the process of agreeing the grid code requirements. There are exceptions to this, such as the ability to ride through faults, which may take significant development effort and time.

This strategy would have some implications for the questions raised by CER/Ofreg on wind penetration. If entirely successful, the technical limit for overall wind penetration levels on the island will be set by the generation adequacy requirements of the power systems alone. (Naturally local transmission requirements for individual wind farms will still be a factor).

However, while this strategy is simple to implement and police from the TSO perspective, and is cost reflective, it will not be the economically most efficient for the island of Ireland. It makes little sense to compel wind farms (whose fuel source is 'free') to perform frequency regulation or provide spinning reserve when these services can be more economically provided by some of the conventional generation, even taking into account the increased operational costs for these other plants.

For clarity, it must be stated that, this does not mean that TSOs are being unwise in seeking wind farms to have the capability to produce reserve (or other ancillary services). TSOs have duties to prudently cater for a range of situations (multiple forced or scheduled outages of conventional power plant providing reserve, low load periods with high wind generation, local transmission difficulties, stability considerations, etc.) where it may be necessary from a security stand point to dispatch such a source of reserve.

The draft proposals from the Scottish TSOs is that renewables (especially wind) production will not be curtailed in any way until the capabilities of the other generation sources have been fully utilised. However the wind plant must still have the ability to be curtailed.

Some wind project developers and manufacturers may react negatively to the requirements presently being outlined by TSOs. They may consider these are barriers to increasing the penetration of wind power onto the system. In fact in the long term they are the opposite, as they will facilitate a greater level of wind penetration and maximise the use of the resource. However in the short to medium term there are certain dangers. This strategy will impose extra costs (capital and O&M) on project developers. There will have to be an investment of time and effort by wind turbine manufacturers and project developers in assimilating and understanding the requirements. There is a chance that some of the requirements will be unduly onerous or costly, or be too far ahead of the developing technology.

On balance the dangers outlined above are heavily outweighed by the long-term benefit of this strategy – maintaining system reliability and facilitating a greater penetration of wind power on the system. Nonetheless the dangers are real and significant in the short term. They can be mitigated. Recommendations for mitigation in an Island of Ireland context are included below.

2.2 Views of interested parties

2.2.1 Discussions with regulators

The Electricity Regulation Act 1999 ('*the Act*') established the Commission for Energy Regulation. Section (9)(4)(f) places a duty on the Commission to have regard to the need to promote the use of renewable, sustainable or alternative forms of energy in carrying out its duty to protect the interests of final customers, while (9)(4)(e) requires the Commission in carrying out this duty to customers to promote the continuity, security and quality of supplies of electricity.

Ofreg's obligations for renewable sources are less well defined than those of CER. The NI Electricity Order only states that the regulator must have regard to the environment in carrying out duties. Ofreg presently promotes renewables as a means of increasing competition in generation and supply.

From early discussions with CER and Ofreg, the project team decided to base the study on three target years, 2005, 2007 and 2010. The decision was made taking into account the timescales for political targets for renewables (2005 and 2010), and the regulatory review timetable (2007) for the system operators.

Further discussions with the regulators will take place as the project progresses.

2.2.2 Discussions with system operators and planners

Meetings have been held with staff from ESB National Grid, NIE/SONI (System Operator for Northern Ireland), and Scottish Power (SP Power Systems).

Both NIE/SONI and ESB National Grid have provided models of the development of the power systems in NI and RoI as envisaged for the study years 2005, 2007 and 2010. They form the basic input data for the analysis that will be carried out in the later stages of the study.

As with any such projections for the future there is no guarantee that they will actually turn out to be accurate. For instance, the models provided by ESB National Grid are not of the envisaged network development. It is important to put these models in the correct context. ESB National Grid were requested to provide network models that meet the applicable planning standards. The models provided include developments that were selected and approved within ESB, following detailed examination. These are listed in the ESB NG forecast statement, 2001/2 to 2007/8 Supplement. With these developments alone the network is unlikely to meet planning standards in all parts of the country. Therefore the models also include theoretical developments in areas where problems have been identified. It is important to note that these theoretical developments have not been through a rigorous examination by ESB NG. Their inclusion here does not indicate that they will be required, nor indeed that they are achievable by a specified year.

NIE/SONI are engaged in a separate study specifically for the NIE system. This study is due to report soon. The concerns of NIE which are to be addressed in the study are weighted towards dynamic issues. This study is likely to provide useful conclusions for the current work. Dynamic issues are deliberately excluded from the current work: the intention is to determine whether such issues should be studied in detail in a second phase.

Both organisations have a wide range of concerns. They can be split into three main areas:

Simulation of wind farms

There is substantial work in progress to determine how best to model the wind turbines. System operators expect to use simulations to determine the effect of new generation on their system, but at present there are two problems:

- the power-systems simulation packages do not have suitable models for wind turbines (particularly the wound-rotor induction generators which are not known from other industries);
- the turbine manufacturers are not able to supply suitable parameters.

There are related questions about the necessary degree of modelling of mechanical and aerodynamic effects. These issues are not specific to Ireland and it appears rapid progress is being made, so they will not be studied in detail in this project. The results of work in progress, at UMIST in particular, will be reviewed.

Reliability, variability and forecasting

There is concern about the variability of wind on timescales from seconds to weeks.

Variability on timescales of seconds is a power quality issue and will be addressed in Task 3. Timescales of minutes to hours raise issues of reserve and unit commitment, and appear to cause the greatest concern. These will be studied in detail in subsequent tasks. Variations on timescales of approximately 12 hours or more relate to scheduling of conventional plant, especially for maintenance, and for scheduling of hydro.

The current state of wind forecasting is described under Task 5.

It is recognised that forecasting can assist, but there is concern amongst TSOs that too much hope is being invested by the wind industry in possible future improvements in forecasting. Much of the published work on forecasting is based on hourly data, which is too coarse a resolution to see some of the issues of concern. Reliance on forecasts must be limited until sufficient track record has been established. Even with perfect forecasting, the high ramp rates expected would cause problems. In Task 5, the proposals for control of ramp rate which are currently being discussed will be reviewed to assess whether they will remove this problem at acceptable cost.

Forecasting techniques are expected to improve but rapid improvements (i.e. within a year) in accuracy of forecasts are not expected.

It is accepted that geographical dispersion will smooth out variations, but the operators point to recorded data, from the Eltra system and from Ireland, for periods of days in winter (the time of highest system demand and therefore critical in generation adequacy terms) which show very low winds over wide areas. This issue will also be studied in the subsequent tasks.

Loss of ancillary services

If conventional generation is displaced from the system, services which are currently provided to the system operators (frequency control, fault current, reserve, reactive power and others) will not be available. As noted in 2.1, one option is to demand that all generators look like conventional generators, but this may not be economically optimum. Some services may best be provided by conventional generators, who could be rewarded directly, or markets could be set up (for reserve, for example). Wind generation could choose to buy or sell services to those markets. Almost certainly different solutions will be suitable for different ancillary services.

The meeting with SP Power Systems was held because they appear to be leading the efforts of the system operators in the UK, and their draft proposals (currently in consultation through the Scottish Grid Code Review Panel) are referred to by ESB National Grid. It should be noted that at present, the intention is to have a set of requirements for large wind farms and transmission connections, with the requirements relaxed at several breakpoints as wind farm size decreases.

There have as yet been no meetings with distribution system operators, and the scope of work for the project specifically lays emphasis on the transmission systems as opposed to the distribution systems. Distribution system issues will be addressed in Task 3 (see Section 4).

2.2.3 Discussions with the wind industry

The principal means of consultation with the wind industry for this project is by comment on the deliverables, of which this interim report is one.

However, discussions have been held with representatives of IWEA. There is a particular concern about the uncertainties currently surrounding network connections for large offshore wind farms in RoI, particularly the timescales, support mechanisms, and the regulatory process. They were aware of the proposals for grid code changes, and considered that:

- some of the draft requirements would be difficult and expensive to meet;
- some should be relatively simple and cheap to meet, given adequate time and clarity for turbine manufacturers to develop solutions.

IWEA considered that wind developers would be willing to accept contractual arrangements under which wind farms could be 'constrained', i.e. output limited by the system operator, under specific operating conditions. These operating conditions would be expected to occur infrequently (for example, high wind farm output coinciding with low-demand periods on summer nights). IWEA consider this principle could significantly reduce connection and network reinforcement costs, with an insignificant effect on annual production.

IWEA also considered that the potential benefits of further interconnection with the GB system are important.

Of the current proposals for revisions to the Grid Code, IWEA identified fault ride-through as a significant issue, and stated that wind turbine manufacturers were understood to be working on technical solutions.

2.3 Characteristics of project developers in Ireland

There is significant diversity in the background of wind project developers active in the Irish market, north and south. There are three broad classes:

- individuals (usually with a farming background) who wish to locate a single turbine on their land;
- developers from a variety of backgrounds interested in projects of several turbines, in the range 5 to 50 MW, and probably seeking connection to the distribution system;
- large organisations aiming to develop large offshore wind farms (and large onshore wind farms, if possible) for connection to the transmission system, as well as smaller onshore wind farms.

The smaller organisations have fewer resources, less technical understanding of the issues surrounding network connection and operation, and less ability to keep up with and contribute to regulatory and commercial developments.

A fourth class may emerge at the smallest end of the market in Northern Ireland, due to incentives for agricultural and rural enterprises to install very small wind turbines (tens of kilowatts). This class would need significant help in dealing with connection issues, amounting to ‘hand-holding’ or simplified procedures. However the effect of this class on total wind production and its contribution to meeting targets is expected to be small, and so it is not considered further in this study.

This diversity presents a significant challenge to regulators and TSOs. The needs of these distinct groups have to be addressed when interfacing with the ‘industry’ and the disparity in resource and technical knowledge allowed for.

2.4 Administration and business process issues

During consultation with project developers in the RoI the perceived difficulty of getting a connection to the transmission system was raised. It is clear that some groups have found the connection process at the transmission level to be slow. When questioned more closely as to why this perception exists the following suggestions were given:

- Administrative procedures unsuited to the new demands placed on them
- Overly legalistic interpretation of the connection process
- Lack of resources in the TSO devoted to processing customer connections
- Requirements written for conventional generation.

It must be noted that these comments are based on past experience, with a set of procedures not designed to cope with the type and volume of enquiries which have been experienced, and some developers may not yet be aware of any recent improvements in the process.

Wind farm developers worldwide generally hold similar views of the connection process, at both distribution and transmission levels. It should be noted that system operators generally can also list some difficulties in dealing with wind farm developers:

- Project developers can have unrealistic expectations of the timescales for network reinforcements
- Project developers are concerned with a particular project, and do not see the ‘big picture’, i.e. the system operator’s general responsibility to all users of the system

- The level of technical information provided, and the confidence that can be placed in it, can be lower than for conventional generation.

If the ambitious targets for wind power set by the policy makers on the island are to be met, it is clear that the connection process must not be seen as a barrier. CER has already consulted on and approved a document published by ESB [2] which is a guide to connection to the ESB distribution system. Comments on possible improvements to this document would be welcomed by CER. An equivalent document for the transmission system is in draft form.

In Northern Ireland, as a result of the Trading and Renewables Implementation Group (TRIG), issues regarding the transparency and complexity of connection arrangements and charges have been recognised. Ofreg plan to work with NIE on further means of clarifying the connection process especially for small wind producers. These developments are likely to remove some of the difficulties facing wind developers, and may reduce the demands on the TSOs.

2.5 Revision of Grid Codes

As noted above, ESB National Grid in its role as TSO in the RoI has produced a draft paper, which is under consideration by the CER, specifying connection requirements for wind farms. This is a timely development as some provisions of the existing grid code are unsuitable for wind generators. At present wind project developers rely on acquiring derogations from the existing grid code to connect to the transmission system. Rightly or wrongly this is viewed by some sections of the wind industry as a difficulty for wind projects, introducing elements of delay and uncertainty, making projects more difficult and expensive to fund and complete. Recommendations to mitigate this view are listed below.

2.6 Recommendations

The following recommendations are based on discussions to date, and are given in the spirit of facilitating a greater penetration of wind power on the electricity system on the island of Ireland, on the timescales envisaged by Government, without negatively impacting present levels of reliability. They are not ranked in any particular order of importance.

1. It is clear to all parties involved in the industry that **modifications to the grid code** to accommodate the development of larger scale windfarms connecting to the transmission system are required. ESB National Grid in the RoI has started this process internally. This would eventually lead to modifications to the Grid Code through the Grid Code Review Panel. This is likely to be a contentious process with complex issues to be resolved. In an effort to bridge the gap between the requirements of the system operators and the technical solutions potentially available to wind turbine manufacturers and project developers, the Regulators should organise (or sponsor) **industry seminars**.

2. In advance of the completion of 1 above, the Regulators should develop procedures by which **Grid Code derogations** for wind projects are processed. Because of the present necessity for all wind projects connected to the transmission system in RoI to secure a derogation, the process is seen as slow by developers. It is understood that procedures are currently under development within CER and should be completed, to provide a clear procedure while modifications to the Grid Code are being considered..

3. The self-provision of vital **ancillary services** such as frequency regulation and operating reserve by wind farms is an area of debate. While there is little doubt that the provision of such services is necessary when large-scale wind farms are connected to the transmission system the manner of their provision must be examined in more detail. The

present strategy being put forward internationally by TSOs reflects a move towards compelling the **self-provision** of these services. Some TSOs have recognised the fact that given the fuel source, this is not the most economic choice. Some go as far as stating that wind farms will only be compelled to provide these services as a 'last-choice' option. However they still insist on the investment in the capability. Before any move is made in this direction in an island of Ireland context a rigorous **examination of alternative options** should be undertaken. This analysis should consider both technical and economic factors and in particular should examine the feasibility of developing a market place where such services (or a subset of services) can be reliably purchased (by or on behalf of wind farms) rather than self-provided. It is understood that Ofreg are reviewing how ancillary services are to be dealt with under further market liberalisation in the North.

4. The concept of **contestability** (the ability for generators to construct their own connections to the power system, for adoption by the system owner) has just been introduced for renewable energy projects in the RoI, for the transmission system only. This is an option that many project developers will find attractive. However there are several critical documents and business processes which must be created in order to implement this concept. These include legal contracts, business process for design approval, and business processes associated with approval of contractors. The regulator should take action to ensure the timely creation of these necessary documents.

5. Criticism has been directed by some industry participants at the **connection process** in the RoI. No process is perfect and resources will always be finite. Given the valuable experience built up in the last few years, it is timely for the system operators to initiate an internal **business process reengineering exercise**. In parallel, an **examination of the resource levels** devoted to this area of the business should be carried out, particularly as finding and employing suitable staff cannot happen overnight. This should increase the efficiency of the overall process and facilitate the smoother processing of the many MW of wind power projects that are predicted in the coming decade. In NI, extensive use is made of outside contractors, paid for by the applicants, but working under the direction of the system operator and reporting jointly to the system operator and applicant. This addresses the resourcing issue in a flexible manner.

6. An **annual customer service survey**, carried out by a professional external body should be initiated. This will give an avenue for more focussed (and hopefully constructive) criticism of the manner in which system operators interact with the wind industry. The concept can be extended to other system users. A properly acted upon, professionally structured approach to eliciting criticisms, suggestions and feedback can be a powerful responsive way for system operators to address the issue of customer service.

7. It is widely acknowledged that an important factor in a power system's ability to accommodate greater levels of wind penetration is improved techniques, experience and ability in **forecasting wind power output**. Pilot schemes are presently underway in RoI and NI. Regulators should ensure that these efforts by system operators are supported and financed properly, and that ultimately they become a permanent feature in control centres in Ireland. Some thought should be given to **a collaborative project** involving ESB National Grid and SONI. ESB National Grid and SONI should closely monitor international developments and best practice in this area.

8. At present ESB National Grid produces a **generation adequacy statement**. The latest version covers the period 2001-2007. In that statement detailed account is taken of projections for energy production from renewable sources including wind. As wind penetration increases in the coming years it will become even more important that the contribution to adequacy of wind is modelled as accurately as possible. This is an area of considerable academic interest with much research activity. It is recommended that:

- The **generation adequacy of the island as a whole be assessed** on a regular basis.
- International developments in modelling the contribution of wind energy to generation adequacy are monitored, and that a range of techniques are studied with a view to **incorporating the latest developments** into the process.

2.7 Summary

At present the installed capacity penetration level of wind generation on the island of Ireland is approximately 2.4%, meeting approximately 1.5% of the gross electricity consumption. If the renewable energy strategy being promulgated by both jurisdictions is successful the capacity penetration level is predicted to rise to about 16% by 2010.

Three 'target years' have been chosen for the subsequent tasks (2005, 2007, and 2010). These dates are based on the timescales of current renewables policies, and the regulatory timetable for price control review.

The current levels of wind penetration are visible, in terms of impact on the power system, to the TSOs in Ireland, and the operators have serious concerns about the anticipated increases.

The island of Ireland is possibly unique, in facing high wind penetration on an electricity system that has only a relatively low-capacity link (the Moyle interconnector) with other systems. Denmark, northern Germany and windy areas of Spain have relatively high-capacity links to other areas. Other 'island' systems with high wind penetration are smaller and have diesel generation, which is much more flexible than conventional large generators. This raises technical issues, for which a range of technical, commercial and regulatory solutions appears to be available.

The operators are engaged in pilot programs to improve their short and long term forecasting capability. This will definitely be useful in dealing with some of the issues identified.

Having considered the detrimental impacts of high levels of wind penetration on the reliable operation of power systems elsewhere, TSOs are calling for the adoption of a prudent approach, through grid code requirements. This will require an investment in and development of new technology by wind project developers and wind turbine manufacturers, and may imply significant costs. However the costs are at present not considered so high as to threaten the targets for wind generation.

If the wind industry can respond successfully to these new technical requirements the only technical limit, aside from local transmission/distribution limitations, to overall wind power penetration on the island will be set by the requirement to maintain a generation adequacy standard acceptable to customers. This is an important theoretical conclusion: the study team has not yet reached any conclusions about the feasibility or the desirability of making wind farms behave almost exactly like conventional generation.

Some recommendations are made, primarily on administrative issues, which should at little cost assist in the process of achieving the targets of Government.

Based on the work done so far, the following preliminary conclusions can be drawn for the six 'key questions' listed in the Request for Tenders (see Section 1).

1. ***What is the feasible level of wind penetration, which can be safely and securely accommodated given the existing RoI and NI transmission systems and plans for their reinforcement?***

No level can determined at this stage. This will be addressed in tasks 4 and 5.

2. *How is this level determined at the moment by the respective transmission system operators?*

There is no procedure for determining an acceptable level. TSOs consider each proposed development on its individual merits, including its effect on the electricity system. There have as yet been no proposed projects of sufficient size to raise transmission system issues, and so systematic procedures to address these issues have not yet been developed.

This is partly because the operators are aware that some of the issues they are concerned about can be solved at additional cost, and so the issue becomes one of equitable determination and allocation of costs. It is also partly because the situation is changing rapidly: some of the issues may be resolved relatively rapidly and cheaply through additional requirements imposed by Grid Code modifications. Only now is information becoming available to allow TSOs to address these issues.

3. *What are the potential impacts of increased wind generation on system reliability and power quality?*

Power quality issues in general are gaining in importance, in particular harmonics, voltage steps, and flicker. It is difficult to see how wind generation can have an effect on power quality at the transmission system level, although ESB National Grid has expressed concerns. Power quality is of concern at the distribution level, particularly voltage fluctuations, and this will be addressed in Task 3. Reliability definitely is an issue. This is discussed in Section 2, and will be investigated in subsequent Tasks.

4. *What are the economic costs and benefits of accommodating increased wind generation?*

This is an issue for Tasks 3 to 6. However it is clear that the costs lie principally in the following areas:

- Transmission (and distribution) system reinforcement (reinforcement can be required for several separate technical reasons)
- Provision of additional functions (primarily control functions) by the wind turbine manufacturers and wind farm developers
- Curtailment costs if wind is curtailed for operational reasons
- Forecasting functions for system operators, and associated instrumentation and telemetry
- Provision of ancillary services currently provided by conventional generation, if that generation is displaced
- Increased requirement for some ancillary services (e.g. reserve), even if the conventional generation currently in place is not displaced.

Potential benefits to be considered are:

- Reduction in system losses (though not all wind developments will result in reduced losses)
- Environmental benefits
- Helping to meet Kyoto obligations
- Fuel source diversity, in particular reduced dependence on gas
- Improved reliability due to the distributed nature of the generation
- Gradual increase in generation capacity which may match load growth better than large conventional generation developments.

5. *What are the potential impacts of increased wind generation, in terms of both price and quality of supply, on final customers?*

In principal, if wind generation becomes cheap enough, the impact in a competitive market will be reduced costs for final customers. Wind costs continue to reduce, but it is clear from point 4 above that there will also be additional costs as wind penetration increases.

In addition, if wind penetration increases above a certain rate, conventional generation plant will be affected in two ways:

- load factors will reduce and greater startup, shutdown and load following will be required, leading to reduced production and higher operating costs;
- in the limit, it will be forced off the system earlier than anticipated, leading to costs for 'stranded assets'.

On the other hand, if international or EU trading in 'green certificates' proceeds, project owners in wind-rich countries will receive income. Depending on the regulatory regime, some of this value could flow to electricity consumers in the wind-rich countries.

Given this background, it will not be possible to say in Task 6 whether costs for final consumers will rise, or by how much, but it is intended to evaluate the effects in more detail and quantify where possible.

The systems are currently operated on the principle that there should be no reduction in quality of supply to final customers, and there seems no reason or impetus to change this principle. All factors that affect quality of supply are calculable, though there may need to be development of procedures to reflect adequately the characteristics of wind.

6. *Are there any other factors which will potentially impact on the ability of the system to handle increased amounts of wind generation?*

No other factors have yet arisen.

3 TASK 2: WIND RESOURCE & WIND FARM LOCATION

Assumptions on the size and location of wind energy projects are required to inform network modelling in later tasks. Numerous studies have quantified the wind energy resource for parts of the Republic of Ireland and Northern Ireland, and, rather than repeat such an exercise, the emphasis in this study is to draw on relevant recent and ongoing work. However it is worth repeating here that the island has an excellent wind resource.

Policy issues are addressed in Section 3.3.

This section summarises relevant resource studies and other pertinent activities, and makes recommendations for assumptions to be employed in the network modelling exercise. Comment on these assumptions is welcome.

3.1 Previous work

3.1.1 Onshore Wind

European Wind Atlas. 1989 [3]

Data from 10 meteorological stations in the Republic and one in Northern Ireland formed the basis of broad estimates for 50m agl (above ground level) annual mean wind speeds. Wind speeds are illustrated as bands on a map, the general pattern of which were informed by large-scale weather patterns. While relief-induced variations are not mapped, relative wind speed up- or down-scaling within each band is presented for five different topographic conditions.

Wind speeds are generally highest for the west and north coast, and lowest inland of the South east corner of Ireland (around Kilkenny, Laois, Offaly and Tipperary), although eastern and central hills and ridges and coastal areas are assumed to have higher wind speeds than areas of the west with sheltered terrain.

Total Renewable Energy Resource in Ireland. 1997 [4]

For the Republic, onshore 45 m agl wind speeds for each 1 km square were estimated from meteorological station data used in the European Wind Atlas. Wind speeds varied according to nearest meteorological station, elevation, land/water surface roughness differences and slope orientation. Squares were populated with 600 kW turbines up to 9 MW/km^2, and energy yield estimates derived for the:

- theoretical resource (entire land populated with turbines);
- feasible resource (removal of built-up and other technically-infeasible areas);
- and accessible resource (further removal of environmentally-constrained areas).

Only those squares with wind speeds of 7 m/s or above were considered. Results for the accessible resource by county are reproduced in Table 3.1.

	Capacity (GW)	Energy (TWh/yr)	% energy
Cork	7.4	45.3	13.1
Kerry	9.0	24.5	7.1
Meath	9.8	23.8	6.9
Donegal	8.4	22.4	6.5
Wexford	8.1	19.9	5.8
Tipperary	6.9	18.2	5.3
Cavan	6.8	17.0	4.9
Wicklow	5.3	15.1	4.4
Westmeath	6.3	15.0	4.3
Laois	5.5	14.4	4.2
Monaghan	5.8	14.4	4.2
Kildare	5.0	12.6	3.7
Kilkenny	5.0	12.1	3.5
Waterford	3.9	10.0	2.9
Offaly	4.0	9.5	2.8
Leitrim	3.3	8.1	2.4
Clare	3.0	7.5	2.2
Sligo	3.0	7.5	2.2
Longford	3.1	7.4	2.1
Limerick	2.6	7.0	2.0
Carlow	2.7	6.7	1.9
Louth	2.6	6.5	1.9
Roscommon	2.7	6.3	1.8
Galway	2.0	4.9	1.4
Dublin	1.7	4.4	1.3
Mayo	1.8	4.4	1.3

Table 3.1 Accessible resource from [4]

High wind speeds were modelled along much of the west and north coast, as well as for large areas of Wicklow and parts of Waterford, Tipperary and the border between Laois and Offaly. Environmentally sensitive areas do tend to coincide with high wind speed areas, reducing the modelled accessible resource in these counties.

Renewable Energy in the Millennium. The Northern Ireland Potential. 1999. [5]

Figures for the onshore wind resource in Northern Ireland are taken from [6], (dated 1997), which uses the ETSU-modified NOABL UK database of 1 km square wind speeds to estimate the resource under a variety of scenarios. It gives a technical resource of some 106 TWh/yr and an accessible resource of 56 TWh/yr. A breakdown by county is not provided, but the NOABL wind speed map shows higher wind speeds in hilly areas across the region (see Figure 3.1 below, where the highest wind speeds are shown in red).

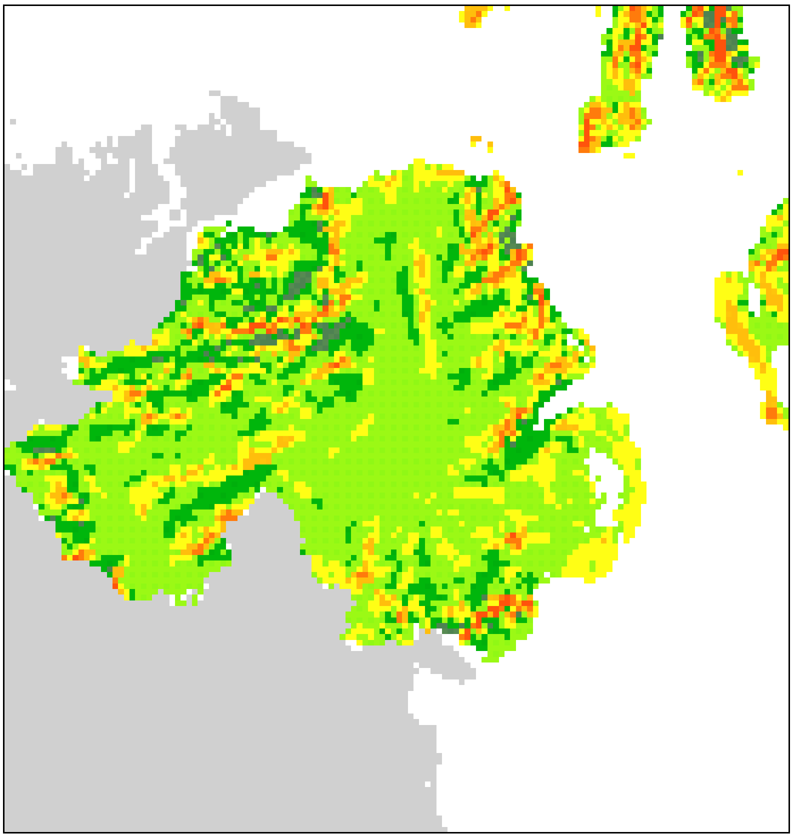

Figure 3.1 Northern Ireland NOABL wind speed map.
(© ETSU for the DTI)

A Renewable Energy Development Strategy – Wind Energy [7]

Resource estimates were made for the Irish Central Borders area, defined as Armagh, Dungannon and Omagh Districts and County Fermanagh in Northern Ireland, and County Cavan, Monaghan, Sligo, Donegal and Leitrim in the Republic of Ireland. A wind speed for each 1 km square of the study region was estimated on the basis of site altitude, extrapolating from some on-site measurements in the area. Energy yields were derived for unconstrained and constrained scenarios (the latter constrained by practical considerations and environmental designations). Results are reproduced in Table 3.2.

	Unconstrained (TWh/yr)	Constrained (TWh/yr)
Donegal	58.4	18.3
Omagh	18.5	7.5
Cavan	14.4	7.0
Fermanagh	15.3	6.6
Sligo	10.6	6.3
Leitrim	13.9	6.3
Dungannon	5.1	4.0
Monaghan	5.0	3.7
Armagh	3.5	3.2

Table 3.2 Resource estimates from [7]

3.1.2 Offshore Wind

European Wind Atlas

Results for the European Wind Atlas have been extrapolated to produce an offshore wind resource map for Europe.

Assessment of Offshore Wind Energy Resources. (2000) [8]

For the Republic of Ireland and Northern Ireland, data from coastal and inland met stations were used to derive coefficients for mathematical modelling of offshore wind speeds. Contours of 50 m annual mean sea level (amsl) wind speeds out to 12 nautical miles offshore (territorial waters) are presented. Energy yields were derived for 1.65 and 3 MW turbines at a spacing of one machine per 500x500 m square for a number of distance offshore and depth-limited scenarios. A summary of the results is shown in Table 3.3: development is assumed to take place up to the water depth shown, and at, or further than, specified minimum distances offshore.

Water depth [m]	Distance from shore [km]	1.65 MW turbines		3 MW turbines	
		Energy NI (TWh/yr)	Energy RoI (TWh/yr)	Energy NI (TWh/yr)	Energy RoI (TWh/yr)
50	2	20.9	142	36.9	264.2
50	4	14.4	96.9	25.4	170.5
50	7	8.6	59.4	14.8	104.9
20	2	3.7	31.5	6.5	55.5
20	4	1.1	14	2	24.5
20	7	0.3	7.1	0.6	12.4

Table 3.3 Offshore resource summary

While the study does not attempt to identify specific sites, depth is a determining criterion with the majority of shallow (up to 20 m depth) sites situated on the east coast of Ireland.

Assessment of the Wind Resource off the East Coast of Ireland, 2001. [9, 10]

Meteorological station data from the European wind atlas was used to initialise the widely-used WaSP wind flow modelling package. A 500 m grid of 50, 75 and 100 m wind speeds was generated for the area of interest – namely out to 20 km offshore from Dublin to Wexford, which takes in four of the five foreshore licensed blocks in the Republic of Ireland. Capacity and energy yields are then estimated for each exploration block based on 4, 2 MW turbines per km^2. The results are reproduced in Table 3.4 below.

Exploration Block	Capacity (MW)	Energy (TWh)
Kish & Bray	320.0	1.2
Codling & India	1696.0	6.2
Arklow	304.0	1.1
Blackwater	544.0	2.0

Table 3.4 Offshore resource estimates for the East coast

3.2 Work underway

Irish Wind Energy Atlas

The work for this study is now complete. It basically updates the Irish section of the European Wind Energy Atlas, employing additional monitored data to initialise the modelling. A publication date is not available. Further information can be found in [11].

Irish Wind Energy Digital Atlas

The Department of Public Enterprise, Ireland, issued a tender in September 2001 for production of a map-based digital wind resource database for the Republic and Northern Ireland. Objectives as stated in the tender were to make use of modelled and monitored data, and be readily updatable, and interactive with other geographical information such as protected areas and grid information. A contract has recently been awarded to ESBI and Truewind.

Northern Ireland resource and grid study

Commissioned by the Northern Ireland Department of Enterprise, Trade and Investment (DETI), administered by Northern Ireland Electricity (NiE) and overseen by a Steering Group, a study is underway to generate up-to-date renewable energy resource estimates for Northern Ireland, and to consider the grid-related constraints to accommodating this resource. A key outcome will be a recommended achievable 2010 target for renewable-generated electricity. The study is being undertaken by PB Power, and the steering group is chaired by Nick Jenkins at UMIST. A report on the non-technical findings is anticipated in mid-July, with a final report to follow later.

3.3 Policy considerations

3.3.1 Background

Republic of Ireland

In its Green Paper on Sustainable Energy [12], the Irish Government set a target of an additional 500 MW_e of renewable energy for the period 2000-2005. Most of this is expected to come from onshore wind. This is in addition to AER III projects which were not commissioned at the time of the Green Paper. The AER (Alternative Energy Requirement) competitive bidding process results in the award of power purchase contracts, under which all the output of the wind farms are purchased at guaranteed prices for up to fifteen years.

To date, projects have secured finance to build wind farms on the strength of:

- A 15 year AER Power Purchase Agreement
- an EU ENERGIE (formerly THERMIE) Power Purchase Agreement plus grant aid
- a sales agreement with a licensed green electricity supplier having access to 100% of the electricity market.

AER and European grants involve direct intervention and a form of subsidy. The 100% 'third party access' (TPA) to customers is afforded to renewables in the Electricity Regulation Act, and is the closest of the three options to the "open market".

Some commentators have suggested that Government will intervene through the use of AER contracts and European-funded projects with a view to bringing on line the full 500 MW for 2005, with any TPA projects additional to this. However, the Green Paper does suggest that TPA projects will be included in the 500 MW target. Government has not explicitly stated its intentions in this respect. It is possible that subsidies may fall away as technologies demonstrate competitiveness.

Figures presented by the Government-convened Renewable Energy Strategy Group show that the 500 MW target (which is for all renewables) is expected to culminate in Ireland's total installed capacity of wind reaching some 601 MW in 2005. To date, 125 MW of onshore wind is operational, with a further 354 MW with planning permission and a recently-awarded AER V contract (see below).

Government has stated that it will review the situation on an ongoing basis and set longer-term targets accordingly. As more TPA projects are developed, one option for government is to concentrate targeted support on less competitive technologies such as offshore wind, wave and biomass. However it is not yet clear if the TPA mechanism as constructed at present is a viable long-term route to market for onshore wind.

In the medium-term, adoption of a green certificate mechanism may prove attractive – especially in view of prospective European and possibly international green certificate markets.

The EU *Directive on the Promotion of Electricity from Renewable Energy* (2001) detailed indicative targets for each of the Member States for 2010. In Ireland's case, the target for electricity produced by renewable energy in 2010 is 13.2% of gross electricity consumption. This would require an additional target of approx 400 MW from renewable energy for the period 2005 – 2010. If this all is provided by additional wind farms, then wind generated electricity will contribute 10.4% of Ireland's electricity needs by 2010 (and 15.4% of installed capacity). No national target has yet been announced for this period, although the National Climate Change Strategy states that *'significant further expansion will be required.....having regard, inter alia to targets at EU level.'*.

Northern Ireland

Nearly 37 MW are operational in Northern Ireland, all of which supply under a NI-NFFO contract and which represent 100% of the wind energy contracts awarded under the two NI-NFFO rounds. Additional projects are under development to supply anticipated new markets.

A consultation [13] issued by DETI in 2001 requested views on the future support and direction for renewable energy in Northern Ireland. A variety of support mechanisms for electricity generating technologies were discussed, with two key choices arising – a continuation of the NFFO model or a green certificate trading scheme. Latterly (February 2002), the Northern Ireland Assembly has reported on its "Energy Inquiry" [14], recommending *inter alia* the introduction of a GB-compatible Renewables Obligation, and targets for 15 and 35% of electricity supply to be met from renewables by 2010 and 2020 respectively.

3.3.2 Recent policy developments

AER V

In February 2002 the Department of Public Enterprise provided details of wind farms with a combined installed capacity of 354 MW that had secured Power Purchase Agreements under the AER V scheme. These projects will mark the first significant step in reaching the 500 MW target by 2005. Table 3.5 below shows the spread of wind energy projects across counties.

County	Capacity [MW]
Carlow	2.6
Cavan	24.3
Clare	32.1
Cork	22.1
Donegal	26.7
Galway	69.3
Kerry	39.3
Leitrim	11.9
Limerick	41.5
Mayo	21.3
Offaly	6.0
Roscommon	7.7
Sligo	38.0
Tipperary	6.2
Waterford	1.6
Wexford	3.6

Table 3.5 AER V results by county

Foreshore Licences

The Irish government Department of Marine and Natural Resources has issued foreshore licenses for seven locations, mostly off the East coast of Ireland, from County Louth down to Wexford, and more recently for locations on the Galway and Kerry coasts. One site – Arklow Bank off Wicklow – now also has a foreshore lease for construction of a wind farm. Subject to gaining necessary environmental and other clearances, construction is planned in four phases as shown in Table 3.6, up to a total of 520 MW by the end of 2006.

Phase	Capacity (MW)	Commissioned
1	60	1 December 2003
2	60	1 December 2004
3	160	1 December 2005
4	240	1 December 2006

Table 3.6 Arklow Bank proposed timetable

A number of additional applications for foreshore licences are pending. Based on information from developers, the combined offshore capacity under development may be as high as 2,000 MW.

Crown Estate Lease

The UK's Crown Estate has recently (February 2002) launched a competition to bid for an option to develop on offshore wind farm in one area off the North coast of Northern Ireland.

At Tunes Plateau, north west of Portrush, County Derry, the development must be between 150-250 MW.

Construction is proposed in three phases, starting December 2005 and finishing December 2007, although this is an indicative timetable and subject to proposals from the successful bidder.

Steering Group on the Grid Upgrade Development Programme

Set up by the Irish government in fulfilment of one of the recommendations from the "Strategy for Intensifying Wind Energy Deployment" [15], this group is presently considering allocation of National Development Plan Funds for grid upgrades. To inform the choice of grid upgrades to facilitate wind energy, the group has, through advertisement, solicited information on proposed wind energy developments across Ireland. This information has been made available to the present study by county. Due to confidentiality, further aggregation was required for presentation here, which is shown broadly by Province, but allowing for Northern Ireland as one area – see Table 3.7 (where 'PP' is planning permission).

Area	Full PP (MW)	Lodged PP/Appeal (MW)	Pre-PP (MW) [1]	Total (MW)
Connacht + Donegal	179	89	977	1245
Leinster + Cavan +Monaghan	47	44	103	194
Munster	135	107	371	613
TOTAL	361	240	1451	2052

Table 3.7 DPE aggregated onshore wind projects

[1] Developer intends to submit planning application in 2001/02 + pre-planning stage projects + projects of unknown status

Northern Ireland trading arrangements for wind

Ofreg are implementing new renewable trading arrangements for wind. Papers issued on the Renewable Output Factor (ROF) are now available on the Ofreg website. New arrangements are to be implemented on 1st July 2002.

3.4 Summary

The context described in this chapter will be used to focus analytical effort in the remaining tasks of the present study. It will also allow results to be set against anticipated real increases in wind energy. Employing for the most part the DPE data, and known onshore projects in Northern Ireland and offshore projects in both jurisdictions, a working reference for each scenario year is proposed. Due to confidentiality, only aggregated data (broadly by Province, but allowing for Northern Ireland as one area) can be shown – see Table 3.8. Data is held at county level, and will be referenced against a database of transmission nodes contained within each county. Comments are invited from interested parties.

Area	Existing	2005 additional (1)	2005 cumulative	2007-2010 additional (2)	2007-2010 cumulative
Connacht + Donegal	90	268	358	976	1334
Leinster, Cavan +Monaghan	3	1272	1275	968	2243
Munster	32	242	274	371	645
Northern Ireland	37	78	115	578	693
TOTAL	162	1860	2022	2893	4915

Table 3.8 Ireland scenario years context (figures in MW)

(1) Full Planning Permission + Planning Permission lodged/appeal + 2 (of 5) East coast Ireland offshore projects.
(2) Projects near to submission plus more tentative projects notified to DPE or known to Ofreg + further 2 of Ireland East coast offshore projects + Northern Ireland North coast offshore project.

4 REMAINING TASKS

The remaining tasks and the proposed methodology proposed are described briefly below, in order that interested parties can be aware of the scope of this work. The text below is an edited version of the proposal for this work.

4.1 Task 3: Distribution system constraints

Having established the areas where wind generation is most likely to locate, the effect of distribution system constraints will be evaluated. These constraints are more clearly understood than the other constraints described in Tasks 4 and 5, and so less effort will be expended on this task. The aims of this task are

- to identify those technical issues that are dominant on the ESB and NIE systems in the areas where wind farms are expected to be developed (different issues are expected in different areas);
- to estimate how much generation can be connected in these areas before problems are experienced (i.e. before significant costs are incurred for network reinforcement or other technical solutions);
- to estimate the costs of removing each of the important network constraints;
- and to estimate how much wind generation will be 'released' by the removal of each of these important constraints.

One of the solutions to some of the possible network constraints is to curtail wind generation at critical periods ('constraining off'). This will be costed as for other possible solutions.

Power quality issues will be addressed in this task, based on the new IEC standard on power quality characteristics of wind turbines.

Note that offshore wind farms are expected to connect to the transmission systems and so are excluded from this task.

4.2 Task 4: Transmission system limits

4.2.1 Aims

This task is similar to Task 3, for the transmission systems. However as these issues are more complex, more effort will be expended.

As for Task 3, the aims are to:

- establish the wind capacity possible without significant expenditure on reinforcement;
- estimate the costs of removing each of the dominant constraints;
- estimate how much wind generation will be 'released' by removing each dominant constraint.

Experience with offshore wind farms elsewhere indicates that wind turbine manufacturers can, if required, provide some control functions and improve dynamic performance at little cost. These features can include:

- the ability to control reactive power to assist in voltage control
- the ability to ride through system disturbances
- limits on power ramp rates
- limits on power output
- short-term frequency regulation actions.

The benefits of these features in overcoming some of the constraining factors will be evaluated. In view of the interest shown in this topic in the initial consulations in Task 1, an attempt will also be made to estimate the costs to project developers in providing these features.

This task is broken down to a number of sub-tasks:

Connection Methodology
In this sub-task the consortium will examine whether the methodology currently employed by ESB National Grid and SONI, to evaluate the impact of connection to the transmission system of large generators, is the most appropriate for very large scale wind farms.

The deliverable from this sub-task will be suggestions, if necessary, for changes to the study methodology employed for very large-scale wind farms. This will take into account the high degree of unpredictability and variability of the power output, and the features of prime mover and generator technology, which differ from those of conventional generation.

Assessment of impact of level of wind penetration on existing and planned transmission system
Early in the project, interviews will be conducted with relevant parties in ESB National Grid and SONI to establish the methodology they employ to evaluate the expected impact of wind penetration on system reinforcement plans. In parallel, the consortium will carry out a desk-study of best international practice in this field.

The deliverable from this sub-task will be a report identifying any significant differences between local and best international practice. It will evaluate any benefits that could be gained by:

- Coordinating the existing approaches adopted by SONI & ESB National Grid.
- And modifying local methodologies in the light of best international practice

Evaluation of capacity of present and planned transmission system to absorb wind power
At present the power system is planned and operated to satisfy predetermined criteria. In this sub-task the consortium will estimate the maximum level of wind penetration, in three target years (2005, 2007, 2010), which will not infringe these criteria or significantly alter the programme of investment.

Information from Task 2 will be used to place wind generation on the networks until constraints are infringed.

The deliverable for this sub-task will be a report indicating the estimated level of wind penetration in years 2002, 2005, 2007 and 2010, which can be accommodated without altering investment plans or infringing planning criteria.

It should be noted that the results of this element of the task are expected to differ from data presented in forecast statements produced by the TSOs, for several reasons:

- there will be differences in the network data used (see Section 2.2.2);
- the analyses will be based on different assumptions;
- there may be local limitations which the analysis in this study will not include.

The assumptions and methodology will be made clear so that the TSOs may, if they wish, be able to determine the reasons for any differences in results.

4.3 Task 5: Impact of wind penetration on power system operation and ancillary service costs

An area of concern to system operators is the impact that large-scale wind farms can have on the operability of the power system. The principal issues are voltage stability and frequency regulation. This study will evaluate the scale of these issues and propose potential solutions.

Voltage stability, which is essentially a local phenomenon, is readily identified at the connection planning stage. It can be easily mitigated at reasonable expense by combination of WTG technology and system reactive devices (e.g. static var controllers), the costs of which can be included in the shallow connection costs of the individual project.

The impact of large-scale wind farms on power system frequency stability is a system wide effect. Its prediction, avoidance and mitigation are complex tasks. A great deal of information exists on the statistical variability of wind speeds. Much knowledge and experience has been gained on the reaction of large-scale power systems to changes in generation levels (e.g. faults, trippings etc.). However, little analysis has been carried out linking changes in wind speed (and the consequent changes in power output levels of wind farms) to the impact on frequency stability.

The consortium will:

- Carry out a desk top study to identify studies linking wind farm output variability to impacts on power system frequency stability
- Assess the historical record of highly variable loads (e.g. Arc Furnaces) and their impacts on the ESB and NIE systems.
- Small fluctuations in system load result in small variations in system frequency which are accommodated by automatic generation control (AGC). However a very large wind farm will introduce variations in frequency which are too large to be accommodated in this way. The size of wind farm is related to the size and dynamic response of the power system. A study will be performed to estimate, for the Irish system (ESB and NIE), in the three target years, the threshold size of wind farm above which special provision (other than existing levels of AGC) must be made. A portfolio of possible counter measures will be identified and costed.

The prospects for wind forecasting will also be reviewed in this Task. The current situation is as follows.

State-of-the-art real-time forecasting of wind energy uses a modeling chain to predict wind energy for look-ahead periods of, typically, up to 48 hours. Existing model systems feed wind speed and direction from the relevant national meteorological offices' Numerical Weather Prediction (NWP) models into a separate model, which is used to localize the wind speed and direction for a range of reference sites. From these reference sites the models use simple up-scaling algorithms to calculate the power production of larger areas. There have been several models developed, but only a few have been used for real-time forecasting so far.

The prediction of wind over land is difficult and complex. This is mainly due to turbulence in the lower boundary layer. The accuracy of predictions is also limited because the lower boundary conditions of operational numerical weather prediction (NWP) models differ significantly from the actual earth's surface due to inadequate horizontal resolution.

Met services can accept larger errors in their modelling of wind over land than a wind energy forecasting system can bear. As a result, existing NWP models have difficulties in more complex terrain, such as Ireland, where the changes in wind speed are highly correlated to the topography. Local effects such as tunnel effects in valleys or roughness changes cannot be modelled accurately, because these are not represented in the coarse topographical representation of the surface in operational NWP models.

In general there are two types of model that use input from the met services numerical models to take account of local effects and then convert wind speed to power. These are linear flow wind models (also called mass-consistent models), and statistical models of time series analysis type or artificial neural networks. There are three models currently being used by Transmission System Operators in real-time. Recently another type of model was presented that computes wind power inside the numerical weather prediction model instead of outside in a model chain.

One model (Predictor) was developed by Risø National Laboratory and uses a physical flow model plus a correction model to account for local effects in a wind farm. It also converts wind to power output. The flow model was originally developed to estimating the wind resource and has been used in the development of the European Wind Atlas. The model was tested for the first time online by ESB National Grid in 2001 .

The second model, WPPT (Wind Power Prediction Tool), is based on advanced time series analysis techniques to cover any systematic mismatch of the NWP model and the turbine measurements. It does not use any knowledge of the physical flow around the turbines. This approach was developed at the Institute of Mathematical Modeling at the Technical University of Denmark. It is being used by a Danish utility and has been online since 1997.

A third model approach for wind energy forecasting was developed in the Institut für Solare Energieversorgungstechnik (ISET) in Germany in conjunction with the University of Kassel and makes use of artificial neural networks (ANN). The model is based on a selection of representative wind farm groups, equipped with wind and power measurement. The ANN model is ‘trained’, using past wind and power data, to recognize the relationships between variations in the wind and the power output of the WTs. It has been operational since summer 2001 in a German utility (E.ON Netz). A major constraint however with neural networks is that the kernel used is too simple, i.e. too many parameters are required to calibrate the models. Therefore, it was found to be very time consuming and data intensive to set up a robust adaptive parameterizations, which is necessary when dealing with weather characteristics. A two year calibration period was necessary.

Linear flow models can only be used in homogenous terrain and the statistical models usually need 3-6 months learning period to adjust the statistics to a certain area. Also because of their linear or even non-physical structure they cannot account for climatological aspects if the input data is from a coarse NWP model.

The results of tasks 3, 4 and 5 will show the wind generation that can be connected to the systems without significant capital or operating costs, and estimates of the costs and benefits (in terms of increased wind capacity) of removing the dominant constraints.

4.4 Task 6: Economic factors

4.4.1 Economic effects

Tasks 3, 4 and 5 are concerned with technical assessments of the effects of increasing wind penetration beyond that which can be accommodated by the existing network (and firm upgrade plans). This task attaches economic costs and benefits to the effects on, and implications for, the network and the system as a whole. It will be necessary to distinguish between costs which apply to all generation, and those which apply only to wind.

Cost assessment will include consideration of:

- New network capacity required to accommodate anticipated increases in wind energy
- Network modifications required for active and passive management of increased wind penetration
- Other generation costs such as reserve or reactive power generation
- Any early plant retiral

Benefit assessment will include consideration of:

- Wind farm development, manufacturing and construction market
- Economic value of wind-generated electricity
- Access to green credit markets
- Meeting government environmental commitments

There is no requirement, in this study, for an assessment of so-called external or non-monetary costs and benefits.

4.4.2 Electricity trading and market operation

Increased wind energy penetration will have implications for overall system operation, including dispatch priority. Market effects will to an extent depend on the direction in which the market develops. In E&W for instance, the new NETA arrangements strive towards contracts-driven market operation, where deviations from pre-notified contracted positions incur penalties. The system operator must still maintain integrity, but the costs of market participation for unpredictable generators – principally wind energy plant – are much higher than under previous arrangements (and the value of electricity is lower). UK government is reviewing the NETA arrangements with respect to the viability of participation of renewables plant, which includes consideration of ex-post trading.

Both the RoI and NI markets are moving towards greater liberalisation over the coming years. CER are shortly to start a review of market-trading arrangements, including the ‘green’ market. This process can both take account of, and/or affect the viability of, wind energy. To date, CER and Ofreg have presided over some “niche” market and trading mechanisms intended to facilitate market access for green generators. The future direction for market development should be informed by the characteristics of the Irish markets, aspirations for green energy and experience overseas.

Task 6 will therefore include a review of overseas experience of the operation of wind energy in liberalised markets. It will also review experience to date within the RoI and NI. Implications for market operation in RoI and NI will be reported and informed by this, and the outcome of previous technical tasks, as well as GH’s own in-depth knowledge of the operational characteristics of wind energy.

4.5 Task 7: Reporting and deliverables

The deliverables from Phase 1 are:

- a report summarising the work done and the conclusions, in a form suitable for general publication by CER and Ofreg;
- recommendations for issues for detailed study in a further Phase 2, if justified;
- presentations by GH staff to CER and Ofreg staff, and other interested parties as identified in the RFT.

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