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The Irish “All Island Grid Study” – Methodological Approach and Outcomes

C. Nabe, M. O'Malley, J. Bömer and D. Broad

Abstract-- This paper details the methodological approach and outcomes of the All Island Grid study, which aims to show the impacts of high penetrations of renewable energy in the Irish electricity system. Renewable Generation portfolios with a share of up to 59 % of Renewable energy were examined from the plant dispatch and network perspective as a 2020 snapshot study. The dispatch analysis of various scenarios of conventional generation revealed only minimal restrictions posed by the expected future conventional generation. The examination of network restrictions resulted in a feasible energy penetration of 42 %.

Index Terms-- power systems, wind energy, market design.

I. INTRODUCTION

THE power system on the island of Ireland (Northern Ireland and Republic of Ireland) comprises a single synchronous power system. In a 2020 scenario, the peak load is expected to be 9.6 GW with two interconnectors to the British system (1 GW in total). As Ireland is an isolated system and has very favourable renewable energy resources, how would it cope with the high shares of renewables?

The All Island Grid study aimed to evaluate the technical and economic impacts of high levels of installed renewable generation, and to identify barriers to the deployment of renewables and measures that might be taken to overcome these barriers [1] – [5]. The various parts of the study and the main information flows between them are shown in Fig. 1.

This paper shows the approach, selected methodological issues as well as the most important results of the study. An emphasis is placed on the cost-benefit analysis. An outlook which describes open questions and further research issues concludes this paper.

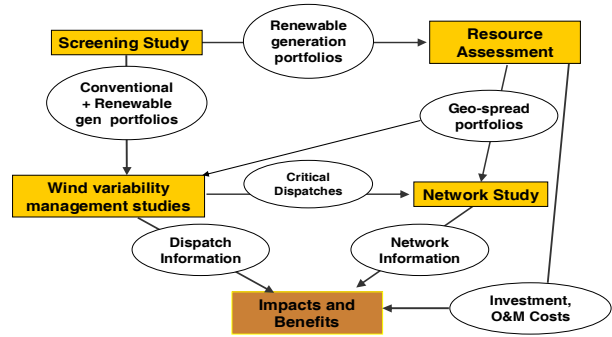


Fig. 1. Structure of the All Island Grid Study

II. THE ALL ISLAND GRID STUDY

The core work streams of the study are the wind variability management study (the unit commitment and dispatch analysis) and the network study. Those two core work streams were preceded by a screening study, which defined the generation portfolios for the following work streams and a resource assessment study. The final work stream performed a comprehensive analysis of the impacts and benefits.

A. Screening Study

To provide a starting point for the main study a screening study was performed to identify the levels of renewables that should be examined in the main study. Six portfolios with shares of renewable generation from 16 % to 59 % and alternative conventional generation scenarios were selected for a detailed examination in the subsequent analysis.

The portfolios selected for the rest of the study may be characterised as follows:

- Portfolio 1 consists of 2000 MW of wind, 180 MW of renewable generation capacity with base-load characteristics (e.g. biomass, biogas etc. but excluding hydro) and 71 MW of tidal energy. Renewable energy is estimated to provide 16 % of the total demand.
- Portfolio 2 contains 4000 MW wind, and the same renewable generation capacity as portfolio 1. The conventional generation includes a relatively high proportion of combined cycle gas turbines (CCGTs).
- Portfolio 3 is a variation of portfolio 2 with a higher share of flexible open-cycle (OCGTs) and aero-derivative (ADGTs) gas turbines and less combined cycle capacity.

All Island Grid Study was conducted by order of The Department of Communications, Energy and Natural Resources (Republic of Ireland) and The Department of Enterprise, Trade and Investment (Northern Ireland).

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- Portfolio 4 is another variation of portfolio 2 but with new coal plants included; Portfolios 2 to 4 have equal renewable generation capacity providing an estimated 27 % of demand.
- In portfolio 5 wind capacities are increased to 6000 MW and additional base-load and tidal energy systems added. Renewable energy penetration is estimated at 42%.
- Portfolio 6 was generated as a result of assumptions of high gas and CO₂ prices and lower prices for wind generators. In this portfolio 8000 MW of wind is installed, together with additional tidal and wave energy capacities. Here, almost 60 % of the electrical energy demand is covered by renewable energy.

The final portfolios used for the analysis are illustrated in Fig. 2 and full details of the screening study can be found in [9].

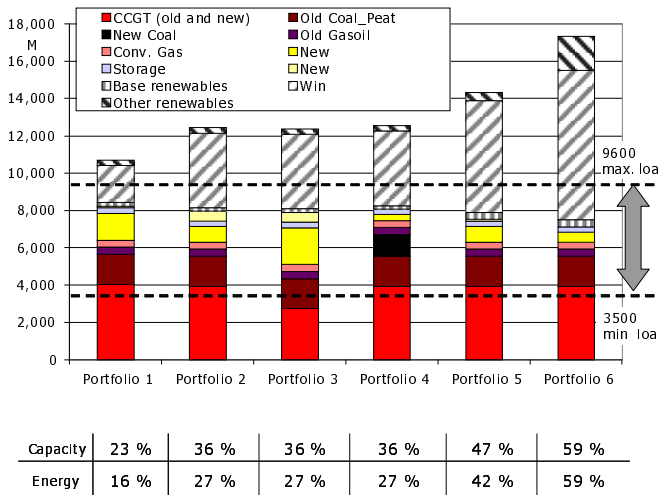


Fig. 2. Generation portfolios as identified in the screening study

B. Resource Assessment Study

The resource assessment study determined the least cost location and quantity of varying levels of renewable resources across the island. Result of this study was a spatial distribution of the various technologies and associated levelised cost for each installation. The cost information is used to determine the total investment and the required level of support. Full details can be found in [2].

C. Network Study

Information about the spatial allocation, derived from the resource assessment study, is used for the study of necessary network upgrades to accommodate the renewable inputs. The network study incorporated a first analysis, based on a DC load flow model in order to identify bottlenecks in the transmission network. Based on this analysis, a number of lines that require reinforcements were identified. Additionally, a security-constrained optimal power flow (SCOPF) analysis was executed for certain critical load flow

situations (minimum load/maximum wind etc). Based on the analysis of these extreme cases control actions such as load shedding and curtailment actions were identified while ensuring N-1 security. The analysis was supplemented with an AC load flow analysis that revealed the necessary measures for reactive power control.

The result from this analysis was a list of lines to be reinforced, static compensation to be installed and the associated cost. Fig. 3 shows that the length of reinforced transmission lines increases dramatically between Portfolio 1 and the others.

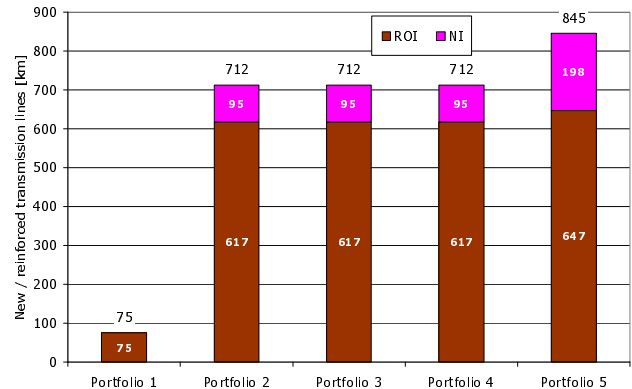


Fig. 3. Generation portfolios as identified in the screening study

This reflects the increase of installed wind capacity from 2000MW to 4000MW. The network study also revealed that installed capacity for portfolio 6 would require a complete network redesign rather than reinforcements of distinct lines. Hence, there is clearly no linear relationship between installed RE capacity and the required network reinforcements, which is an important result for other network integration studies. As the study methodology did not allow for a network redesign further analysis of portfolio 6 were not carried out. The total investment cost varies from €92 million for portfolio 1 to €1,007 million for portfolio 5, including the cost for an additional 75 kilometers to 845 kilometers of transmission lines respectively. This equals a cost of 0.1 to 1.2 €/MWh.

D. Wind Variability Management Study

The aim of the wind variability management study was to investigate the implications of the integration of a high share of generations with a high variability and stochastic output characteristics to the unit commitment and economic dispatch process. Among the outputs of this part of the study are the generation cost, the fuel mix, CO₂ emissions and the dispatch characteristics such as full load hours and number of starts for every generator.

The analysis was based on a chronological unit commitment and dispatch simulation of one wind year. It is important to note that no network constraints were included. The objective of the simulation model was to minimise expected total cost while maintaining the restriction of

operation security with respect to required replacement and spinning reserve levels. Plant characteristics are modelled in great detail, incorporating inflexibilities and part load characteristics. To best cope with the stochastic properties of wind generation on dispatch, a stochastic mixed integer linear optimisation approach was used, and the time-dependent forecasting accuracy of wind and load was represented by discrete scenario trees. A rolling unit commitment and dispatch planning was applied that incorporates the stochastic information and minimises the expected value of total cost. Hence robust commitment decisions like startup or shutdown of plants were calculated to cover load and reserve requirements of the scenarios represented in the scenario tree. The scheduling and scenario tree tool is based on the Wilmar planning tool ([6], [7]), modified with a Mixed Integer Optimisation according to [8]. Further details in [3].

The main result of the dispatch study is that from a dispatch perspective all generation portfolios except portfolio 6 were proven to be feasible. Hence, up to 42% of energy from renewables can be accommodated in the system. For generation portfolio 6 (59% renewables) the methodological shortcomings in the study did not allow further analysis. Another interesting result is that spinning reserve provision from curtailed wind energy generators is not an important measure. The share of wind energy curtailed for reserve provision is less than 0.04% in portfolio 5, and almost negligible in all other feasible portfolios. This shows that the provision of spinning reserve from conventional generators is more cost-effective than the curtailment of wind energy.

III. IMPACT AND BENEFITS

Finally the impact and benefits work stream performed a full cost-benefit analysis. Within the cost-benefit analysis the following cost categories were aggregated for each portfolio:

- Annual Operational cost (fuel)
- Annual Operational cost (CO₂)
- Net payments for imports- and exports with the GB system
- Annualised cost of required network investment
- Annualised fixed investment cost of conventional generation
- Annualised investment cost of renewable generation

Annualised investment cost for renewable and conventional generation and the implications for market design are discussed below in more detail.

A. Financing Renewable Energy Investment

From the renewable resource assessment study and the wind variability management study were gleaned the annualised investment and operation cost for both existing and new renewable generators. The investments have to be re-financed by income from electricity sales at the electricity market. If necessary, support payments have to compensate

the cost gap between revenues and investment financing cost.

To calculate the required support, marginal costs calculated in the commitment and dispatch model were interpreted as prices. Based on those hourly prices, the hourly production and annualised investment cost profit resource curves were calculated. These curves show profitability and required support on a plant-by-plant basis.

Fig. 4 shows the profit resource curve for generation portfolio 5. Obviously, wind energy is by far the most cost efficient renewable resource. It becomes obvious that about 2 TWh of electricity from wind can be produced without additional support. For the remaining generation support payments are required that ranges between 0 and 200 €/MWh.

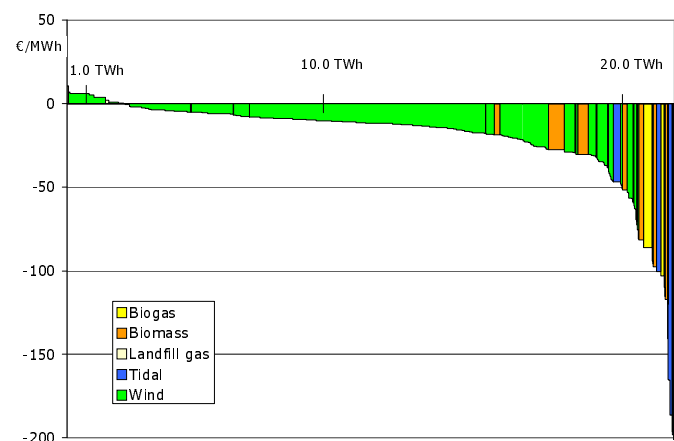


Fig. 4. Profit resource curve for generation portfolio 5

However, this perspective assumes “perfect support schemes” contributing only the difference between cost and revenues. In reality practical implementations of support schemes (such as feed-in or quota schemes) lead to windfall profits that increase the required support.

As the required support payments are depending on the price levels at the electricity market, which in turn, are depending on the fossil fuel mix, there is an interaction between electricity price level, support level for renewables and investment in conventional generation. These interactions should not be neglected from a long-term policy perspective.

B. Investment Cost of Conventional Units

A similar analysis can be made for conventional generators. For those generators fuel, costs for CO₂ and other operational costs are deducted from generators’ revenues.

Fig. 5 shows that expected revenues of new conventional plants will not cover investment cost in most cases. Exceptions are new aeroderivative gas turbines (ADGT) and new open cycle gas turbines (OCGT) in portfolio 5. This shows the importance of peak-load capacities in high-penetration scenarios.

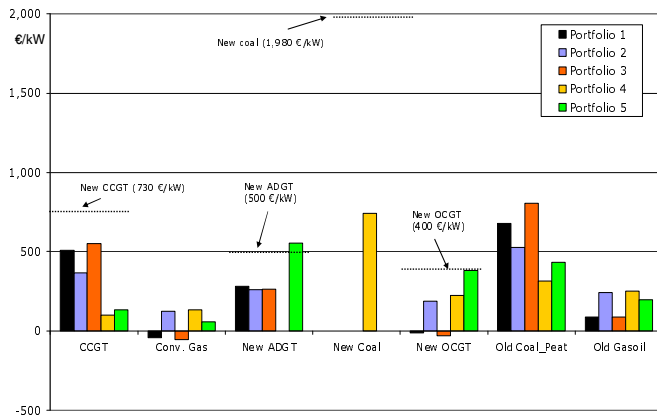


Fig. 5. Specific capital investments in generation plants that can be financed from available cash flow. Additionally indicative investment cost for new plants

On the other hand it has to be kept in mind that no specific market design was assumed in this analysis. Hence, the calculation does not include payments for capacity provision. These payments may support the provision of generation capacity.

C. Total Societal Cost and Benefits

The total additional costs for society of generation portfolios 1-5 are shown in Fig. 6.

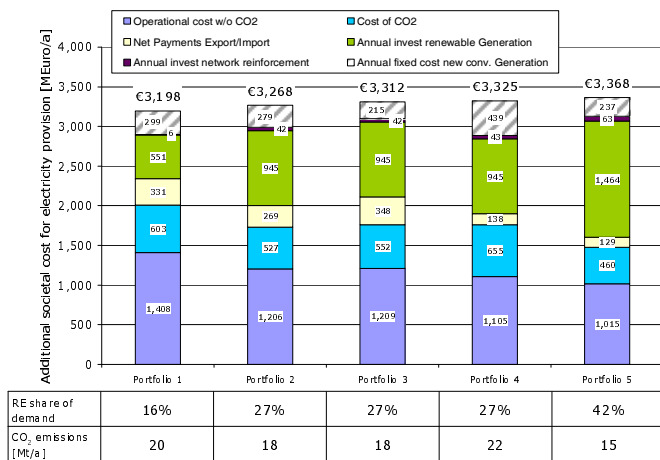


Fig. 6. Additional societal cost for electricity provision in M€/annum

As expected, the lower operating costs of the scenarios with higher penetration of renewables are balanced by annual investments for renewable generation. Shares of investment costs from conventional generation and net payments for ex- and imports vary with the plant mix. From the cost perspective annualised investments in transmission are only of minor importance but the political and societal difficulties of building it may add substantial delays and other costs. Comparing portfolio 1 and 5 it becomes obvious that a reduction of emissions by 25 % can be achieved by increasing the energy share of renewables from 16 % to 42 %. The total cost increase is below 6 % with respect to the cost categories

included in this analysis.

IV. FURTHER RESEARCH

So far, the commitment and dispatch model was based on an hourly dispatch. Intra-hour variations of wind and the impact on required plant flexibility have not been analysed yet. Hence, a further analysis should include this aspect to assess, whether intra-hour adjustments have implications for the economic dispatch and security of supply.

The study examined six discrete portfolios as a result of a screening study that involved a simple optimisation algorithm. In the light of the results of the more detailed analysis in the subsequent work streams, a further optimisation of the structure of both renewable and conventional generation should be attempted. The low infra-marginal rents of the conventional generators described in section III.B indicate a potential for optimisation of the shares of the different plant types.

On 1st November 2007 a Single Electricity Market (SEM) was established on the Island of Ireland. SEM achieved integration of two previous market designs (Republic of Ireland and Northern Ireland) into one common trading platform for wholesale electricity across the island. The market is organised as a mandatory gross Pool with day-ahead complex bidding and a central dispatch with constraints payments. The All Island Grid study did not assume a specific market design. However, it is clear that a detailed study should examine both impacts of a market design on generator’s revenues and market design implications of rolling dispatch, involving a stochastic optimisation. These impacts have to be examined in further research.

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- ESB International, Dublin
- Electricity Research Center, University College Dublin
- Risø National Laboratory, Denmark
- IER at the University of Stuttgart
- TNEI, Manchester

VI. CONCLUSIONS

The Irish All Island grid study demonstrates the basic feasibility of incorporating up to 42 % of renewable energies to a power system with only a limited connection capacity to neighboring power systems both from the dispatch and network perspective. Although the network costs seem to be low, the actual required effort should not be underestimated. Furthermore, a detailed analysis of intra-hour system behaviour and market design issues should be undertaken.

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VIII. BIOGRAPHIES



Christian Nabe obtained a degree of Industrial Engineering and Management from the Technical University Berlin/ Germany. He also studied in the MBA programme at the University of British Columbia Canada and received a PhD in energy economics from Technical University Berlin. Presently he works as a senior consultant in the Power System and Markets group at the Ecofys office in Berlin. Before this assignment he collected more than four years experience as a management consultant in the utility sector. His specialties include the Interaction of Renewable Energy Systems with power markets (including regulation and balancing markets), support schemes for renewables and the regulation of electricity network operators.



Mark O'Malley is the Professor of Electrical Engineering at University College Dublin (UCD) and the Director of the industry supported Electricity Research Centre (<http://ee.ucd.ie/erc>). He has received two Fulbright awards and two UCD President's Research Fellowships. He has spent sabbaticals in University of Virginia, University of Washington and in the National Renewable Energy Laboratory, Colorado. He has authored over 150 academic papers, supervised 14 PhDs to completion and is a Member of the Royal Irish Academy, Fellow of the Institute of Electrical and Electronic Engineers (IEEE), Fellow of the Institution of Electrical Engineers (IEE) and a Fellow of the Institute of Engineers of Ireland (IEI). He is a member of the Engineering Sciences Panel of the European Research Council and a Member of the IEEE Ethics and Member Conduct Committee. He is a technical consultant to the All Island Grid Study and regularly consults to clients in the Electricity Industry.



Diane Broad, P.E., has worked as a utility systems engineer, primarily designing substations and grid interconnection facilities for generation at 69-kV, 115-kV and 230-kV. She also worked on design and integration of electrical system protective equipment. She holds a BSEE from Colorado State University.

Ms. Broad presently works as a senior consultant in the Ecofys Power System and Markets group from her office in Corvallis, Oregon, USA. She was employed in 2000-2001 as a consultant with Ecofys in The Netherlands. In that time, she was responsible for projects implementing wind and solar power systems in grid-connected applications. In her current position, she is taking on projects in the US and abroad.

Ms. Broad has served as a technical resource to state regulators and policy-makers in the effort to streamline the interconnection process for small renewable energy generators in the state of Oregon.



Jens Bömer works as a Consultant in the Power Systems and Markets group at the Ecofys office in Berlin. He is responsible for power flow and dynamic grid studies and manages several projects on innovations in electrical power systems. Due to his former work experience he has thorough knowledge about the intersection between technical and political decision making.

Before Mr Bömer joined Ecofys in September 2007, he worked two years as a consultant to the German Environment Ministry and dealt with technical questions regarding the grid integration of wind turbines and other renewable energies.

As Ecofys Consultant he continued advising the Ministry on the regulations to improve the grid integration of wind turbines in the foreseen amendment of the German Renewable Energy Law in 2009. Mr Bömer is currently working on a PhD in co-operation with the Electrical Power Systems group at Technical University of Delft while working four days part-time for Ecofys. He holds a diploma in Electrical Engineering from University of Dortmund where he specialised on power systems and renewable energies.