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The Impact of Electric Vehicles on the Facilitation of Intermittent Renewable Generation on the Irish Electricity System

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I certify that this thesis, which I submit in partial fulfilment of the requirements of the Masters of Energy Management (DT015) of the Dublin Institute of Technology, is a product of my own work and that any content included that relates to the work of other individuals, published or otherwise, are acknowledged through appropriate referencing.

Signed: ___________________________________

Date: _____________________________________

Acknowledgments

Many thanks to my supervisor, Dr. Michael Conlon, for all his feedback and support. It was much appreciated. Thanks also to my colleagues in the ESB for their input.

Special thanks to my husband David for all his help.

Abstract

This project examines some of the advantages the introduction of Electric Vehicles (EV) could have to the Irish electricity system. In particular the ability of EVs to complement high levels of intermittent wind generation in Ireland in 2020 is investigated. Firstly, the implications the additional night time EV charging load has on the facilitation of increased wind generation at night is analysed. Next, the use of the EVs in a storage capacity to provide a back-up generation source to fluctuating wind generation through the use of Vehicle to Grid (V2G) technology is considered. Finally carbon emission and system cost savings achieved through the use of EVs are quantified.

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1 Introduction

The world's wind resources are substantial and have the potential to meet all our energy requirements. However as wind becomes a larger fraction of electricity generation, its grid integration becomes more difficult due to its variability, intermittency and unpredictability. The incorporation of storage or back-up facilities are potential solutions, but dedicated storage and back-up for wind generation results in high capital costs which generally make increased penetration of wind uneconomical. What is required is a cheaper alternative means of storage; the battery technology used by Electrical Vehicles (EVs) could provide the solution for this. The Central Statistics Office (CSO) (2008) state that on average private cars in Ireland travel 47km per day. This means that they are typically in use for less than 3 hours per day, therefore showing the potential they have for being used for other purposes, such as the supply of electric power in the case of EVs, during their idle time.

This potential has been recognised in an Irish context. Professor J Owen Lewis, Chief Executive, Sustainable Energy Ireland (SEI) said at the opening of the Electric Vehicle and Sustainable Transport Conference 2009 "Ireland has a significant renewable energy potential in the form of wind and ocean energy. As these provide a variable supply of energy, with large amounts sometimes available at night time when our system demand is low, electric vehicles charging at night time will allow us to manage this renewable resource more effectively." This sentiment was echoed by the Minister for Communications, Energy and Natural Resources, (DCENR), Eamon Ryan, in his press release in April 2009 announcing collaboration between Government, the Electricity Supply Board, (ESB) and Renault-Nissan to ensure EVs on Irish roads within two years and an EV target of 10% by 2020. Minister Ryan explained that Ireland has one of the highest penetrations of wind in Europe and that this renewable energy resource is better utilised in charging EVs which will effectively provide storage facilities for the wind generated at non peak load times.

It is clear from the above that the benefit and potential of EVs in terms of facilitating wind generation on the Irish system is recognised. This project will attempt to quantify this benefit and potential, by analysing the situation in 2020.

Firstly a review of literature on this topic is presented in Chapter 2 with specific research questions identified. In order to carry out analysis of this selected year, assumptions are required to be made on key factors such as the likely amount of EVs which will be in circulation at that time, as well as the likely amount of wind generation. Chapter 3 concentrates on setting this scene for 2020 by forecasting realistic figures for a number of items. Following on from this, analysis of the 2020 situation is presented in Chapter 4. This analysis is broadly broken into two sections. These are:

> 4.1 Facilitation of Additional Wind on the Electricity System: This section contains analysis work carried out to establish whether the inclusion of EVs will allow for additional wind generation on the system
>
> 4.2 Ancillary Services & Back Up Provision: The ability of EVs to provide the reserve and back up to wind generation is investigated in this section

Finally Chapter 5 summarises the findings of the project and also includes recommendations for future work.

2 Literature Review

The review presented in this chapter outlines the impact EV's have had on a number of the world's energy markets. In addition an overview of Vehicle to Grid (V2G) technology is provided together with a summary of the main findings presented in existing literature related to the integration of the technology into a selection of national energy supply systems. A critical analysis of the review is also presented here with this analysis resulting in the identification of a number of research questions which form the basis for further development of this research project.

2.1 Impact of charging EV batteries on daily load profile

Shortt et al. (2009) investigate the impact of charging EVs on future generation portfolios in Ireland, and conclude that centrally controlled charging may result in an increased system demand minimum thereby allowing for further variable renewable generation on the system. They also determine that for systems with large proportions of variable renewable energy, such as Ireland into the future, that controlled charging of EVs may reduce the requirement for curtailment of such generation.

Similar conclusions are drawn by the National Renewable Energy Laboratory (NREL) (2006a) in their preliminary assessment of plug-in hybrid EVs on wind energy markets. Through their analysis of the electricity system in the U.S.A. they establish that "EVs could be a significant enabling factor for increased penetration of wind energy".

Eirgrid (2008) estimate the impact 250,000 EVs could have on the load profile for Ireland in 2020. Figure 2-1 shows the results of their analysis. The red line shows the daily load profile under a "business as usual" scenario and the blue line shows the impact of 250,000 EVs, assuming "smart" control of the charging process to encourage charging during the night time valley.

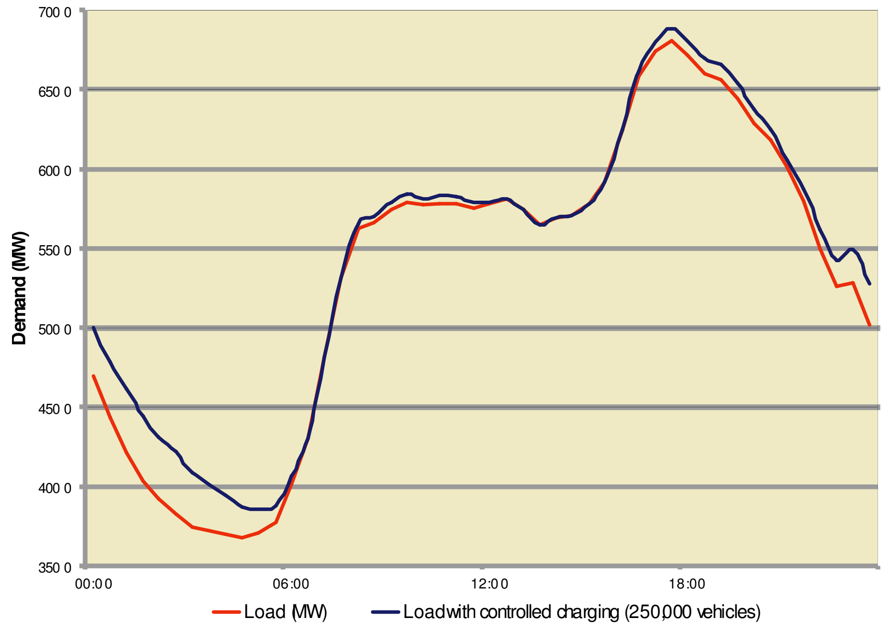


Figure 2-1 Potential impact of 250,000 EVs on the daily load profile in 2020 (Source: Eirgrid (2008))

Modelling work in New Zealand has led to comparable conclusions for what is a relatively isolated island system, similar in many ways to the Irish system. Gibson (2009) reported that the Electricity Commission in New Zealand have forecast that the ability of EVs to smooth the peaks and troughs of electricity supply could "triple the country's capacity to use wind power". Dr. Smith, of the Electricity Commission, explains how this is possible because it ensures that wind energy at night is not wasted, which he describes is currently one of wind power's major inefficiencies.

On a smaller yet analogous system, Pina et al. (2008) look at a case study on the island of Flores in the Azores to establish whether the introduction of EVs on such an island can help increase renewable energy penetration. They found that for such a small isolated system, EVs provide a solution for not only reducing energy dependency and fuel consumption, but also increasing the penetration of renewable forms of energy. The latter is achieved by increasing the base loads of electricity demand shown in Figure 2-2 below.

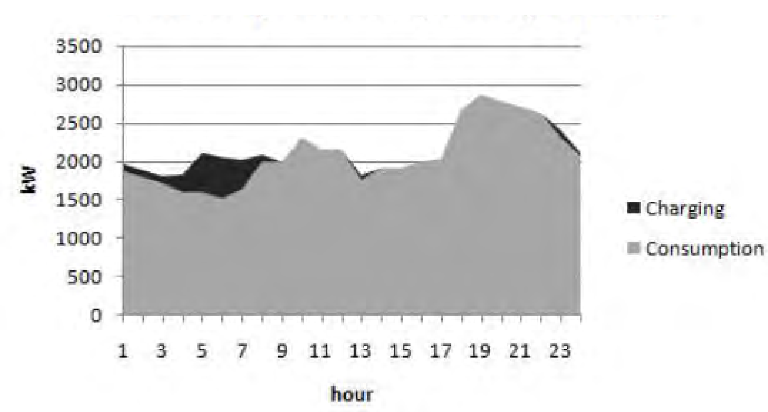


Figure 2-2 Winter production and consumption curves with the introduction of electric vehicles in the island of Flores (Source: Pina et al. (2008))

2.2 Vehicle to Grid Technology

The phenomenon of Vehicle-to-Grid (V2G) technology is explained by Kempton et al. (2006) in their graphical representation of the technology as shown in Figure 2-3 below.

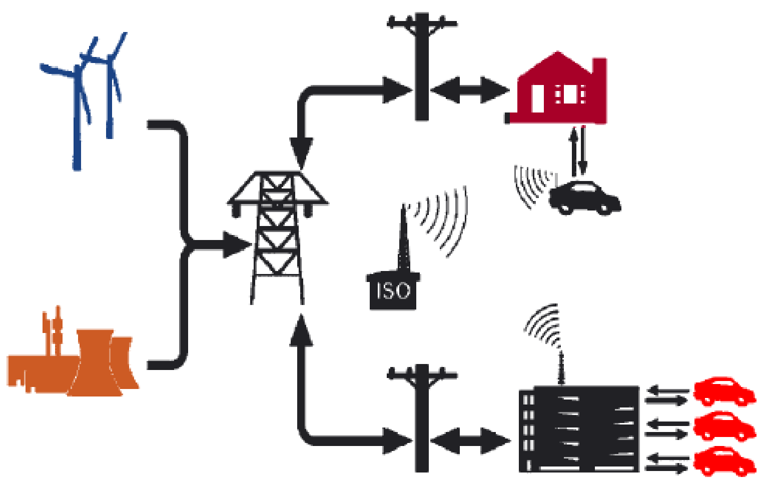


Figure 2-3 Concept of V2G illustrated (Source: Kempton et al. (2006))

The basic concept is that EVs can charge during low demand times and discharge when power is needed. The diagram illustrates schematically the connection between the vehicles and the power grid. Electricity flows one-way from generators through the grid to the EVs and then back to the grid from the EVs in the opposite direction. The control signal from the grid operator, (labelled as ISO, Independent System Operator, in the diagram), sends requests for power to the EVs. This signal could go directly to each individual vehicle or to office of a fleet operator for example. Signals are also sent by the ISO when they want the EVs to charge. This would typically be at night time when there is surplus wind generation on the system.

Kempton et al. (2004b) describe how 3 essential elements are required for V2G:

- a connection to the grid for electrical energy flow
- control or logical connection necessary for communication with the grid operator
- controls and metering on board the vehicle

A lot of research has been done in the field of V2G to see if the potential benefits outlined above are actually realisable.

Turton, H et al. (2007) used an energy-systems model to carry out a detailed and global analysis for the potential of V2G technologies over the long term. Their results showed that V2G had the potential to transform the energy and transport systems in a number of fundamental ways including reducing the requirement for installation of conventional peak generation capacity, and supporting the installation of renewable electricity by helping overcome intermittency problems.

In their examination of the benefits and barriers of EVs and V2G, Sovacool et al. (2008) determine that such technology could greatly improve the economic performance of electric utility companies, especially those that use renewable energy generators such as wind turbines. This is due to the way in which EVs can store electricity produced by wind, and provide the power back to the grid when needed. They conclude that a V2G strategy will help level the daily fluctuations in wind power and could offset the need for fast response, or spinning reserves, which would otherwise be necessary to integrate intermittent generation resources. Marano et al. (2008) also conclude that the integration of EVs into the power grid can "increase the economic viability of renewable sources".

Whether or not EVs can actually replace the need for the build of conventional peak generation capacity or will more simply serve as a provider of ancillary services and reserve in their support of wind generation, seems to be as of yet undetermined. The NREL (2006b) consider the ability of EVs to discharge into the grid to replace conventional capacity that provides peak and reserve capacity. They conclude that while

EVs are best suited to short-term ancillary services such as regulation and spinning reserve, there is also potential for a large fleet of EVs to replace a fraction of low capacity factor conventional generation. Kempton et al. (1999) also find that there is an economic case for EVs for the provision of peak power in Japan when compared with the option of building conventional generation for this purpose.

However calculations carried out by Letendre, S et al. (2002) showed that EVs cannot compete with conventional generation for the provision of base load power, but are economically competitive in provision of peak power, spinning reserves and regulation services. They concluded by saying that "V2G could revolutionise the ancillary services market, improve grid stability and reliability and support increased generation from intermittent renewables". Similarly, Tomić et al. (2007) also recognised the ability of EVs to provide ancillary services to the electricity grid in their study of the grid support that could be provided by EVs.

Studies of the Danish system have also shown that V2G will help with the integration of wind generation. Divya et al. (2008) conclude that EVs will play an important role in achieving the 50% renewable electricity target in Denmark by 2025 through their ability to make operation of the grid more reliable and also by making the integration of renewable generation more economic. Lund et al. (2008) used their EnergyPLAN model to assess the integration of renewable energy into the transport and electricity sectors through V2G in Denmark. They found that EVs with night charging and increased intelligence (including V2G) will improve the ability to integrate wind power onto the electricity system. Figure 2-4 below, taken from their report, shows how the excess production of wind generation decreases as EVs (or Battery EVs BEV) and V2G technology are introduced.

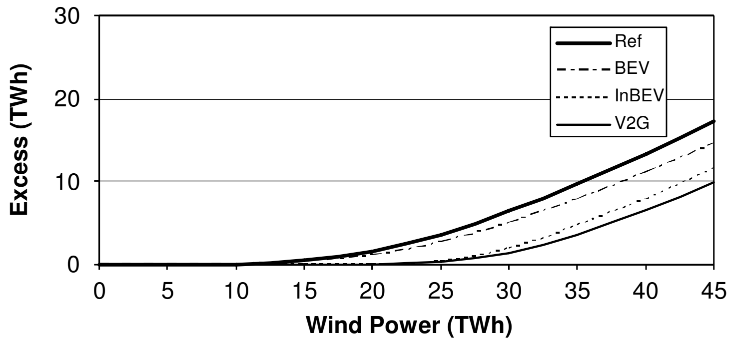


Figure 2-4 Annual excess electricity production as electricity from wind power increases (Source: Lund et al. (2008))

In an Irish context, Kempon et al. (2006) carried out analysis to see the potential for V2G at a national level. The results of their analysis are shown in Table 2-1 below. For Ireland they calculated that an EV fleet at 15kW would produce 846% or about 8 times the average load. They recognise that not all vehicles would be electrified, have V2G or be plugged in and charged at the moment needed, but with the transport sector over eight times greater than electricity demand in terms of energy requirement, there is plenty of scope.

Country	Number of passenger vehicles	V2G @ 15kW from all vehicles (GW)	Average national load (GW)	All vehicles @ 15KW/ average load (%)
Denmark	1.900.370	29	4	805
France	29.218.210	438	50	885
Germany	44.652.517	670	58	1.149
Ireland	1.470.644	22	2,6	846
Italy	33.819.390	507	34	1.473
Netherlands	6.865.832	103	12	888
Portugal	5.807.664	87	5	1.740
Spain	18.714.180	281	26	1.068
Sweden	4.050.273	61	15	407
UK	28.447.908	427	40	1.081
USA	191.000.000	2.865	417	686

Table 2-1 The V2G potential of the light vehicle fleet, compared with load in 11 OECD countries (Source: Kempton et al. (2006))

Eirgrid (2008) noted that EVs could also positively impact the operation of the grid in Ireland. Batteries of EVs could be used as controllable power storage, with the units charged during periods of low demand and returning power back to the grid during peak hours.

Much research has been undertaken on this topic in America. Kempton et al. (2004a) calculated that V2G could stablilise large-scale wind power with a small percentage of the vehicle fleet dedicated for wind regulation. They estimate that for one-half of US electricity to be provided by wind power, 3% of the transport fleet would be required for regulation, with 3-38% of the fleet providing operating reserves and storage for wind. They forecast that in the short term, EVs would be used primarily for the time critical services such as regulation and spinning reserves. In the longer term V2G would serve the market for peak power and storage for renewable generation, with eventually the possibility of perhaps one quarter to one half of the fleet serving as back up generation and storage for renewable energy. Later that year Kempton et al. (2004b) conclude that the societal advantages of developing V2G include "increased stability and reliability of the electric grid, lower electric system costs and inexpensive storage and backup for renewable generation".

In further research Kempton et al. (2006) carry out analysis to estimate how much V2G would be needed to integrate large-scale wind power in the USA. They assume that storage is used to maintain a 20% firm capacity (which roughly represents a firm capacity requirement of two-thirds of an average 33% wind capacity factor). They analyse historic wind profiles to establish how frequently wind power was below 20% of rated capacity and for what duration. The results of this are shown in Figure 2-5 below and show that there were just 342 low-power events during the studied year, the majority of which were for a very short duration.

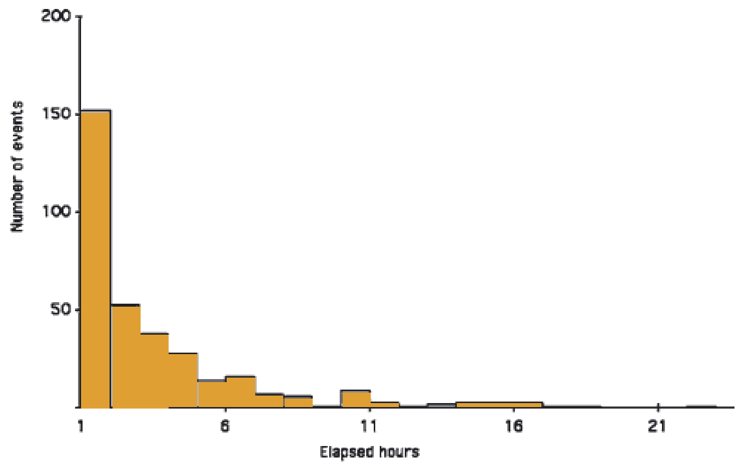


Figure 2-5 Durations of the 342 shortfall events during the year based on historic wind data (Source: Kempton et al. (2006))

Therefore they conclude the majority of storage requirements could be met by relatively small storage that would be called frequently which they say would be an ideal application for V2G.

2.3 Review Conclusions

From the review carried out in Section 2.1, it is clear that the ability of EVs to alter the demand profile shape by increasing night time demand to meet battery charging requirements, could have potential for allowing further integration of intermittent renewable generation, such as wind, onto the Irish system.

Although the findings of the reviewed literature presented in Section 2.2 were not always consistent it is clear that V2G has the potential to facilitate intermittent generation on the system, through its ability to provide ancillary services such as operating reserve to the system. Whether or not V2G technology can actually replace the requirement for conventional generation is still unknown but would appear to be dependent on the scale of the EV fleet. Although a relatively small amount of research has been done in an Irish context, it would appear at the preliminary stage of this investigation that the scale and ratio of the electricity and transport sectors is conducive to V2G as the Irish energy market has similarities with the markets reviewed in Section 2.2. Furthermore, from

Eirgrid's annual publication on generation adequacy, its potential is being taken seriously by key stakeholders.

The following paragraphs outline the main research questions which will be answered in this project. The essence of this project focuses on an assessment of the impact of EVs on the facilitation of intermittent renewable generation on the Irish electricity system. The literature review in Section 2 showed that generally the introduction of EVs does have a positive influence on the ability of an electricity system to absorb large amounts of wind generation. This project will focus on answering this question specifically in an Irish context.

Further questions to be answered include:

- What is the impact of different levels of EVs on the electricity demand profile in Ireland out into the future?

  Eirgrid (2008), have carried out some work on this and this is shown earlier in Figure 2-1. This project carries out similar analysis for various levels of EV penetration.

- By raising the night-time load in Ireland, will this facilitate more intermittent generation on the system? If so, by how much?

  This general conclusion was drawn by Shortt et al. (2009) & is forecast by Gibson (2009) for New Zealand. However a more detailed analysis and quantification, specific to Ireland, is carried out for this project.

- What scale of wind generation would no longer need to be curtailed if there were flexible charging of EVs?

  Lund et al. (2008) saw a decreased in excess wind power in Denmark with the introduction of EVs. Their results are shown in Figure 2-4. Similar analysis is carried out for Ireland in this project.

- From analysis of historic wind profiles in Ireland how frequently are their periods of low output from wind and what are their durations? What level of EVs and V2G would be needed to provide sufficient back up for this?

Kempton et al. (2004a) & (2006) attempt to answer this question for the USA. Their conclusions are shown in Section 2.2. Analysis is carried out in this project to assess the situation for the Irish system.

- What level of ancillary services and reserve back up power could V2G technology provide in Ireland?

  Kempton et al. (2006a) attempt to quantify the potential of the transport sector in Ireland to provide V2G. Their results are shown in Figure 2-5. More detailed analysis is carried out as part of this project.

- Can V2G technology in Ireland provide an alternative to the build of conventional peaking generation?

  NREL (2006b), Kempton et al. (1999) and Letendre et al. (2002) all investigate this question for various locations. This project focuses specifically on answering this for Ireland.

3 Review & Justification of Modelling Assumptions

The focal point of this project is to quantify the impact that EVs may have on the facilitation of wind on the electricity network. The year 2020 was chosen as a future reference point, and all analysis was carried out for that year. Many forecasts and predictions for 2020 were required to be made in order to facilitate this analysis work. This chapter looks at what assumptions were made and the background in deciding upon them.

3.1 Wind Generation

The following sub-sections make predictions for the amount of wind generation which will be built by 2020 and the likely outputs of this generation.

3.1.1 Installed Capacity

There are many different projections for the installed capacity of wind generation, (i.e. the amount of wind generation which will be built), in 2020. The Department of Communications, Energy and Natural Resources (DCENR) together with the Department of Enterprise, Trade and Investment in Northern Ireland (DETI) published the All Island Grid Study (AIGS) in 2008. This study analysed the ability of the electrical power system and transmission network in Ireland to absorb large amounts of electricity produced from renewable energy sources. A range of renewable portfolios were assessed in the AIGS. These are shown in Table 3-1 and graphically in Figure 3-1 below.

		Portfolio 1	Portfolios 2 – 4	Portfolio 5
Renewable Share of Demand	%	16%	27%	42%
Installed MW – Wind	MW	2,000	4,000	6,000
Installed MW – Base Renewable	MW	182	182	360
Installed MW – Other Renewable	MW	71	71	285

Table 3-1 Renewable portfolio options for 2020 (Source: AIGS (2008))

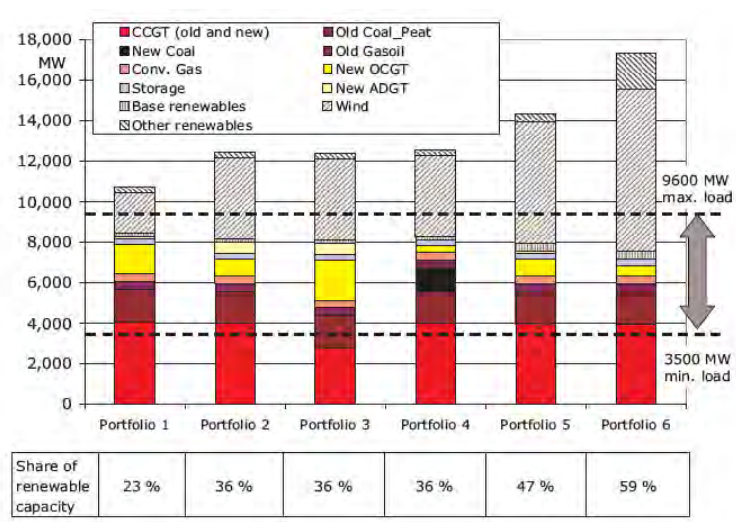


Figure 3-1 Generation portfolio options for 2020 (Source: AIGS (2008))

Pöyry (2009) use Eirgrid's (2008b) strategy document, which sets out the development of the Irish electricity network (Grid 25), as the basis for their forecast of installed wind and renewable energy in the Single Electricity Market (SEM) in 2020. Table 3-2 below has their predictions.

	Wind	Wave	Tidal	Biomass	Other Renewable	Total
Installed Capacity (GW)	6.1	0.1	0.1	0.2	0.1	6.6

Table 3-2 Forecast renewable capacity in 2020 for SEM (Source: Pöyry (2009))

CER & NIAUR (2009) take their assumptions for wind generation directly from the AIGS.

The SEI (2009b) indicates that 5,500MW of wind generation is required in ROI by 2020.

Eirgrid (2008a) estimate there will be 2,900MW of wind generation installed by 2015 in ROI, with SONI (2008) estimating in the region of 950MW in NI for the same date. This gives an approximate ratio between ROI and NI of 75:25

The figures from Portfolio 2-4 from the AIGS were used as basis to compile the assumptions for installed wind capacity in ROI in 2020 for this study and are shown in Table 3-3 below. The AIGS has been well received in the industry and is recognised as a comprehensive view of the electricity system in 2020. Three of the authors of the report shared the Annual Achievement Award from the Utility Wind Integration Group (UWIG) in recognition of their input and leadership in the production of the report. Since this project focuses on ROI only, 75% of the AIGS figure was used, reflecting the ROI:NI ratio.

This assumption will have a significant impact on the outcome of modelling analysis in this report. For this reason two cases, base and high, have been included in the table.

	BASE Case	HIGH Case
Wind Capacity (MW)	3,000	4,500
Note:	75% of AIGS figures used to reflect installed capacity in ROI only	

Table 3-3 Wind generation capacity assumptions

3.1.2 Profiles

The installed capacity figures given in Section 3.1.1 represent the maximum output possible from the wind generation. In reality the output of wind generators is frequently less than this. Wind profile data gives the profile or variation in wind output over a period of time. Values are given from 0 to 100% of rated output. Three sources of wind profile data were investigated for use in this project. They were:

i. Historic wind speed data from Met Éireann

ii. Historic wind generation output data from Eirgrid

iii. Wind profile data from ESB

Hourly wind speed data in (i) is available to purchase from Met Éireann for a fee. However once purchased the data must first be adjusted for the correct hub height of the wind turbines, and next transformed to expected output data using power curves of wind turbines. This would require a significant amount of work given the amount of years that would be required and the various locations. Therefore source (i) was discounted.

Source (ii) represents the actual generation output data for some of the wind farms in the All Island Market and is available free to download from the Eirgrid website in half-hourly format. However, this data is only available from October 2007. For this reason source (ii) was also discounted.

The ESB data (iii) was compiled for the Irish Wind Energy Association (IWEA) and was subsequently bought by the ESB. It represents ten years worth of wind speed data for five locations in Ireland, (originally sourced from Met Éireann), transformed into wind generation hourly output profiles. There are fifty profiles in total, representing the ten years at each of the five locations. Values range from 0 to 1, representing zero to full output. This source was considered to be the best and most readily available and was therefore chosen as the source wind profile data for this project. Average load factors for the fifty profiles range from 19% to 60%.

Note: ESB wind data (iii) is confidential and therefore not available for subsequent use in further studies.

The ESB data is provided for five different locations. These are Malin Head, Dublin Airport, Shannon Airport, Rosslare and Bellmullet. Eirgrid (2008b) forecast the regional distribution of renewable capacity as shown in Figure 3-2 below.

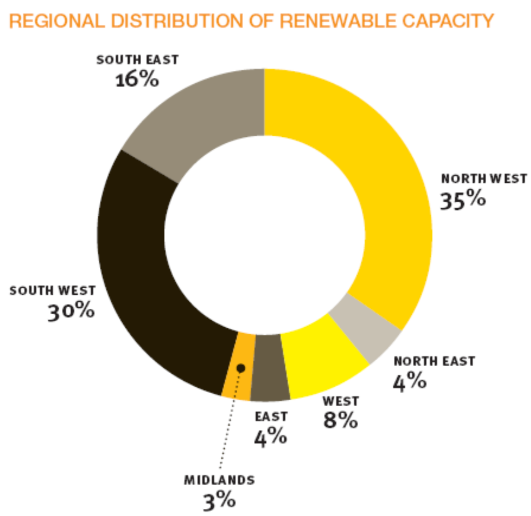


Figure 3-2Forecast regional distribution of renewable generation capacity in Ireland in 2025 (Source: Eirgrid (2008b))

Using this distribution, weightings were assigned to each of the five locations where historic wind profile data was available, giving the results as shown in Table 3-4 below.

ESB 5 Locations:	Bellmullet	Dublin Airport	Malin Head	Rosslare	Shannon Airport
Weightings	23.4%	11.00%	11.40%	16.30%	38.00%

Table 3-4 Locational weightings for wind generation installations

Using these weightings, a profile was created for each of the ten years. Appendix B gives details of the statistical analysis of these ten compiled profiles. Average load factors for the ten years range from 31% to 38%.

3.2 Electrical Vehicles

The following subsections make predictions for the classification type, fleet size, usage patterns, efficiency, charging rate, storage capacity and driving range of EVs in Ireland in 2020.

3.2.1 Classification Type

Three types of classification of EVs exist. They are Battery Electric Vehicles (BEVs), Hybrid Electric Vehicles (HEVs) and Plug-In Hybrid Electric Vehicles (PHEVs). BEVs are powered by electricity stored in large batteries within the vehicles. These batteries are used to power an electric motor that drives the vehicle. HEVs are powered by a combination of electricity and either petrol or diesel. The electricity is used only as an intermediate energy storage medium to improve the overall efficiency of the vehicle, therefore they do not need to be plugged in to recharge the battery. PHEVs work similarly to HEVs in that they can operate using their petrol or diesel engine as well as stored electricity for an electric motor, however, they have much larger batteries than HEVs and can also be charged from the mains when not in use. As such they act as a halfway ground between BEVs and HEVs.

For the purposes of this report the use of BEVs is assumed throughout. It was necessary to focus on a single classification as different technical parameters exist for all three, and analysis of each type would be unwieldy. BEVs were chosen as they represent the closest replacement of conventional vehicles with pure electricity powered vehicles.

3.2.2 Fleet Size

The total number of road vehicles in ROI was 2,138,680 in 2006 according to the SEI (2007b), with private cars and good vehicles accounting for 77% and 14% of this total respectively. This accounted for 63% of the total transport energy demand in 2006 at 3,457ktoe (~40TWh). The Central Statistics Office (CSO) (2008) state in their report on transport statistics that the number of road vehicles had grown to 2.45m by the end of 2007, with private cars and goods vehicles making up 1.89m and 0.34m of this figure respectively.

SEI (2007a) forecast that total energy usage in the transport sector will rise by 14% by 2020, with road freight using nearly 4,000ktoe (~47TWh) by that time. This equates to ~2.6m road vehicles, with ~2m of them being private cars. The SEI (2009b) tell us that the government target of 10% EVs in 2020 will represent approximately 250,000 cars.

Using this information Table 3-5 below was compiled. It shows the assumptions selected for the number of EVs assumed to be in existence in ROI in 2020.

	2020 Assumption	Note
No. of EVs in existence in ROI (BASE Case)	250,000	Assuming approx. 10% penetration level
No. of EVs in existence in ROI (HIGH Case)	*500,000*	*Assuming approx. 20% penetration level*
No. of EVs in existence in ROI (LOW Case)	*125,000*	*Assuming approx. 5% penetration level*

Table 3-5 EV fleet size assumptions for 2020

This assumption is likely to have a large impact on the outcome of the modelling, therefore high and low figures have also been included for the estimate of EVs in 2020 to allow for sensitivity analysis.

3.2.3 Usage Patterns

SEI (2007b) also tell us that the average distance travelled by private cars in 2006 was 16,985km p.a. (or 46.5km per day). They observe a trend that this figure is reducing 0.95% p.a. on average since 2000. The CSO (2008) estimate a similar figure of 17,137km p.a. (or 46.9km per day) as the average distance travelled by private cars in 2007. They too note a decline in this figure from 18,006km in 2002.

SEI (2007c) also carried out a survey to ascertain the usage patterns of road vehicles to establish patterns of energy usage. Although the survey was limited and are not representative of typical Irish fleet, (only eight fleet operators responded) the results are still relevant and of interest for this project. Table 3-1 below has some of the findings from this survey.

Vehicle Type	Total no. of vehicles in response from fleet operators	Average Daily Mileage	Hours away from base	Day or Night Usage?
Car	1,007	40 – 460	6 – 8	Day
Van	3,480	40 – 460	2 – 8	Day
Large Bus	2,620	5 – 250	2.5 – 18	Predominantly Day

Table 3-6 Results of vehicle usage pattern survey (Source: SEI (2007c))

General Motors (GM) (2009) also present us with statistics for average daily distances travelled by car in Europe. These are shown in Figure 3-3 below.

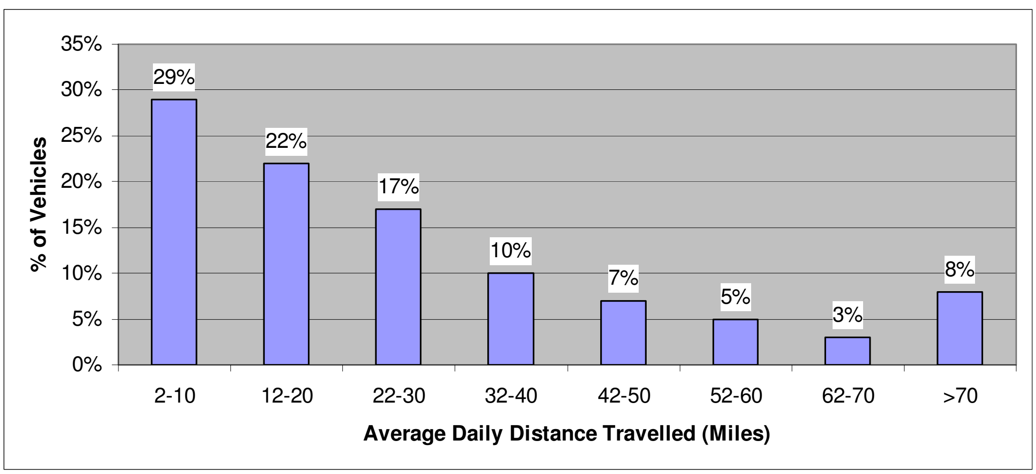


Figure 3-3 European average car daily distance travelled (Source: GM (2009))

Shortt et al (2009) assumed an average distance travelled per car of 50km in their analysis of the impact of EV charging on future generation portfolios in Ireland.

Using the above information Table 3-7 was compiled with the assumptions to be used in this report with regard to assumed annual and daily distances travelled as well as average daily hours away from base.

	Annual Distance Travelled (km)	Daily Distance Travelled (km)	Hours Away From Base
2020 Assumption	17,000	47	7

Table 3-7 EV average distance assumptions

3.2.4 Efficiency, Charging Rates, Storage Capacity & Driving Range

Efficiency

SEI (2007c) give an overview of the range of different battery types available for use in BEVs. They explain that the BEVs typically use between 0.2 to 0.5 kWhs of energy per mile. When compared with a conventional petrol vehicle, which used 0.8kWh of energy per mile, the BEVs are considerably more efficient.

Eirgrid (2008a) assume an efficiency of 10-25kWh/100km (0.1 to 0.25 kWhrs of energy per km) in their analysis of the impact of EVs on the 2020 electricity profile in Ireland.

In a presentation given by Billy Riordan of Mitsubishi Ireland (2009) at the SEI Electric Vehicle and Sustainable Transport Conference in February 2009, he quoted the statistics behind the Mitsubishi iMiEV. The range of this car, which has a Li-ion battery, is currently 160km, with 20kWh of energy required to charge the battery fully. This gives the iMiEV an efficiency of 0.125kWh/km. The "well to wheel" efficiency for the car is quoted at 28.5% compared with 15.8% and 12.4% for the conventional diesel and petrol vehicles respectively. The iMiEV can be charged in two ways; using a fast 3-phase system (200V, 50kW) it takes just 30 minutes to charge the battery to 80% of its capacity, and using a regular charger (200V, 15A) it takes 7 hours to charge fully).

Shortt et al (2009) assumed a daily vehicle energy requirement of 0.2kWh/km in their investigation of the optimal charges of EVs on future generation portfolios in Ireland. In their analysis they considered three charging regimes: slow and fast uncontrolled charging, (which assumes EVs charge at some fixed rate once grid-connected) and controlled charging (which assumes the EVs are charged optimally over the course of the day).

For this report it is assumed that for the base case the discharge rate for the EVs was 0.15kWh/km with controlled charging occurring over a seven hour period at night time.

Charging Rates

At a presentation given by the ESB (2009) at the SEI Electric Vehicle and Sustainable Transport Conference in February 2009, they classified the charging requirements of EVs into three as shown in Table 3-8.

Charge Classification	Requirement	Power
Standard	100% 6-8 hours	3kW
Emergency	24km in 10 minutes	25kW
Fast	80% in 10 minutes	120kW

Table 3-8 Charge classification for EVs (Source: ESB (2009))

The ESB standard charging rate of 3kW is assumed for this project.

Storage Capacity

Kempton et al. (2001) analysed three different battery-powered EVs with differing battery types. The results of this analysis are shown in Table 3-9 below. They show that the energy stored in these ranged from 11.5kWh to 27.4kWh. The average of these figures is 20.9kWh.

Vehicle characteristics	Lead-acid prototype[a]	Honda EV Plus	Th!nk City
Battery type	Pb-acid, 66Ah, 30 modules 12V	NiMh, 95Ah, 24 modules 12 V	NiCd, 100Ah 19 modules 6 V
Energy stored (kWh)	23.8	27.4	11.5
Max Depth of Discharge (%)	90	90	90
Max power to motor (kW)	150	49	27
Eff_{veh} (Wh/mile)	200–250[b]	280–350[b]	217
Efficiency (%) (grid-battery-grid)	74 (93*85*93)	72 (93*83*93)	~80
Max range (miles)	80-100	80-100	53
Battery cycle life (cycles)[c]	1000	1000	1500
Battery calendar life (years)	3-4	5-6	5
Battery cost OEM[d] ($/kWh)	125	300-450	300 (600[e])
Replacement labor, h	10	10	8

[a]- based on prototype vehicles by AC Propulsion, Inc. b- In our calculations we use a median value, that is Effveh=225 Wh/mi for AC Propulsion vehicle and Effveh=315 Wh/mi for Honda EV Plus; c- at 80% depth of discharge; d-Original Equipment Manufacturer (Kalhammer 1995); e- retail cost that individual customers pay for replacing the battery pack (Schon 2001)

Table 3-9 Technical classification of three battery EVs (Source: Kemption et al. (2001))

If you consider a discharge rate of 0.15kWh/km, a driving range of 240km (Telsar Roadster, given in SEI (2007)), and an efficiency of 75%, this gives a potential energy storage value of 27kWh. Shortt et al (2009) also includes some sample EV battery capacities ranging from 16-35kWh.

For the purposes of this study a figure of 20kWh is used for the base energy storage capability. High and low figures of 27kWh and 11kWh are also used for stress testing. Table 3-10 below summarises the assumptions on EV energy storage.

	Energy Storage Capability		
	Base	High	Low
kWh per EV	20	27	11

Table 3-10 Energy Storage Capabilities of EVs

Driving Range

The driving range capability of EVs also varies widely. SEI (2007c) tell us the distance a BEV can be driven before it needs recharging depends on the type and number of batteries installed and can range from 30 to 120 miles. SEI (2007d) give the driving range of the Reva (50-100km) and the Teslar Roadster (240km). Taking an average of these figures and the driving ranges listed in Table 3-9 gives an average driving range of 141km.

Summary

Discharge Rate	0.15kWh/km
Charging Level	3kW
Storage Capacity	20kWh
Charging Time	7 hours
Driving Range	141km

Table 3-11 Summary of EV Efficiency, Charging Rate, Storage Capacity & Driving Range Assumptions

3.3 Electricity System

The following sub-sections make predictions for the 2020 electricity demand, profile and generation portfolio in Ireland.

3.3.1 Demand

Different forecasts for electricity demand exist out into the future. The AIGS gives an estimate of the all island demand at over 53TWh in 2020. Given the current ratio of ROI to NI demand, this would put the ROI and NI demands at 37.6TWh and 15.7TWh respectively.

If the 2015 forecast demand assumptions from Eirgrid (2008a) are extrapolated, (by maintaining average growth rates), out to 2020, then an ROI demand in the region of 34.9 – 42.8TWh is predicted. In a recent publication looking at the impact of wind in the all island market the Commission for Energy Regulation (CER) and the Northern Ireland

Authority for Utility Regulation (NIAUR) (2009) forecast that all island demand would be 59.7TWh in 2020.

The SEI (2007a) forecast ROI demand in 2020 at 39.8TWh in their baseline forecast.

Pöyry (2009) also make predictions for electricity demand in 2020 in their study which looked at the impact of high penetrations of wind generation on the electricity markets in Ireland and Great Britain. They predict demand in ROI to be 33.7TWh.

The demand estimate from the AIGS, (as shown in Table 3-12), was selected for use in this project.

	Base Case
2020 ROI Electricity Demand (TWh)	37.6

Table 3-12 Electricity demand assumptions for ROI 2020

Note: Since these assumptions were made a subsequent publication by Eirgrid (2009d) has indicated that forecast demand assumptions will be lower than previously forecast due to the continuing economic downturn. However, the analysis contained in this report is still valid albeit that the 2020 demand figure used may not be reached until a later date.

3.3.2 Profile

The 2020 hourly demand profile was created using the 2008 half-hourly load profile values as the starting point. The 2008 values were obtained for ROI from Eirgrid.

Table 3-13 below gives some statistics for this data.

	Energy (GWh)	Peak (MW)	SLF (%)	DLF (%)	TLF (%)
ROI	28,992	5,043	81.16%	81.09%	65.81%

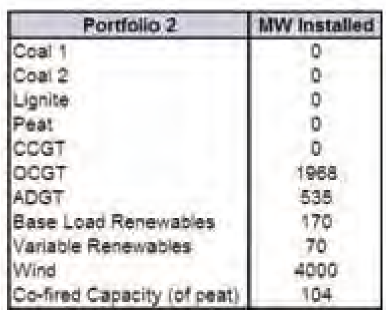
Table 3-13 Electricity profile statistics for 2008

The SLF, DLF and TLF (Seasonal, Daily & Total System Load Factors respectively. For definitions see Appendix E), ratios of the data were maintained for the 2020 curves. The

2020 profile was then created by keeping these ratios the same as the 2008 values but ensuring the overall demand figure was as given in 3.3.1. The hourly load values for 2008 were simply multiplied by a constant, the ratio of the total annual energy demand in 2020 to that in 2008. Using this methodology gives a peak of 6,604MW for ROI in 2020.

3.3.3 Generation Portfolio

The AIGS (2008) gives six possible generation portfolio options for 2020 (as seen earlier in Figure 3-1). To produce the portfolio for this study, Portfolio 2 was used as the starting point. Existing units in NI were firstly excluded. The bulk of the new generation in this Portfolio, (seen in Figure 3-4) was Open Cycle Gas Turbine Technology (i.e. 10 x 103.56MW OCGT & 5 x 106.97MW ADGT) and the amount of wind (4,000MW) was in line with assumptions made previously for this study. A total of 1,000MW was assumed for interconnection in Portfolio 2 in 2020.



Portfolio 2	MW Installed
Coal 1	0
Coal 2	0
Lignite	0
Peat	0
CCGT	0
OCGT	1968
ADGT	535
Base Load Renewables	170
Variable Renewables	70
Wind	4000
Co-fired Capacity (of peat)	104

Figure 3-4 Installed capacity of new generation for Portfolio 2 in both ROI and NI (Source: AIGS (2008))

The new generators was scaled back to exclude any surplus which would have been included to meet NI demand. This was done using the adequacy method described in Section 4.1.3. The generic forced and scheduled outage assumptions used for the plant are given in Appendix F. The amount of new generation was reduced to the figures shown in Table 3-14. This revised amount gave a surplus generation capacity of 76MW which was deemed a reasonable assumption. These portfolio assumptions are used in the adequacy studies in 4.1.3 of this report.

	AIGS Portfolio 2	Pro-Rata Portfolio Assumptions
	(MW)	
OCGT	1968 (19 x 104)	1352 (13 x 104)
ADGT	535 (5 x 107)	321 (3 x 107)

Table 3-14 New generation assumptions

3.4 Carbon Emissions

The following paragraphs describe the assumptions that need to be made in order to calculate the CO2 emission savings possible with EVs.

3.4.1 CO2 Intensity of Electricity Grid

Although EVs themselves emit no emissions, CO2 emissions are created by the generation of the electricity that is used to charge them. (Note: The CO2 associated with the embedded energy of EVs is not being considered in this study). Therefore, in order to look at the potential savings, the carbon intensity of the electricity grid must be taken into consideration. This figure is a function of the type of generation on the system. SEI (2007a) shows that the intensity has been decreasing steadily as both the efficiency of the system and the renewables share increase. In 2007 the figure for ROI was 0.534 kgCO2/kWh.

In 2020 it is reasonable to assume that this figure will have reduced further as renewables will have increased to 40%. The AIGS shows for portfolio total CO2 emissions of 18 MTonnes in 2020. This equates to a carbon intensity of 0.34kgCO2/kWh (given a demand of 53TWh).

Since the generation portfolio for this study is based on Portfolio 2 from the AIGS, the carbon intensity from this will also be taken.

3.4.2 CO2 Vehicle Emissions

The CO2 emissions from cars vary on the model, fuel type, driving pattern and annual distance travelled. Earlier we saw that the average annual distance travelled is 17,000km. From the SEI website the average emissions per kilometre is given as 164gCO2/km. Therefore the average car emits ~ 2,800kg CO2 per annum.

3.5 Summary

Chapter 3 looked at what assumptions were required to be made for the year 2020 in order for meaningful analysis to be carried out. Table 3-15 below summarises the base case numeric assumptions from this Chapter.

Installed wind capacity	3,000MW
EV fleet size	250,000
EV daily distance travelled	47km
EV hours away from base	7 hours
EV efficiency	0.15km/kWh
EV storage capacity	20kWh
EV driving range	141km
Electricity demand	37.6GWh
CO2 grid intensity	0.34kgCO2/kWh
CO2 vehicle emissions	164gCO2/km

Table 3-15 Base case assumptions summary for 2020

4 Implementation: Predictions for 2020

This Chapter contains the analysis work which was carried out in order to answer the research questions identified in Chapter 2.

4.1 Facilitation of Additional Wind on the Electricity System

The following sub-sections investigate whether the presence of EVs on the electricity system in 2020 and the additional load they bring with them, will facilitate additional wind generation.

4.1.1 Impact of charging EV batteries on daily load profile

To analyse the impact of EV charging load on the electricity demand profile in 2020, the business as usual profile for the year was first created as per Section 3.3.2. Following on from this, the load forecast was then adjusted based on the various assumptions regarding EVs, which are detailed in Section 3.2. Table 4-1 shows the increase in annual demand as a result of the EV load on the system, and also the nightly MW increase, assuming a seven hour controlled charging period at night time. As can be seen the night time load is increased by ~252MW as a result of the night time charging of 250,000 EVs. The low and high EV penetration cases give increases in night time demand of ~126MW and ~504MW respectively.

	2020 Forecast Annual Demand (GWh)	No. of EVs	Increase in Annual Demand (GWh)	Increase in Night Time Load (MW)
Base	37,600	250,000	643	252
Low		125,000	322	126
High		500,000	1,287	504

Table 4-1 Changes in electricity demand resulting from EV load

Figure 4-1 graphically shows the forecast electricity demand for a typical week day in 2020, under the business as usual scenario with no EV load. Load forecast scenarios are also shown for base, low and high penetration levels of EVs. Note: The graph below is cumulative, e.g. at 4:00am the demand in the High EV case is 4,000MW which is 504MW greater than the business as usual scenario, and the sum of the three extra portions on the graph and not just the pink portion.

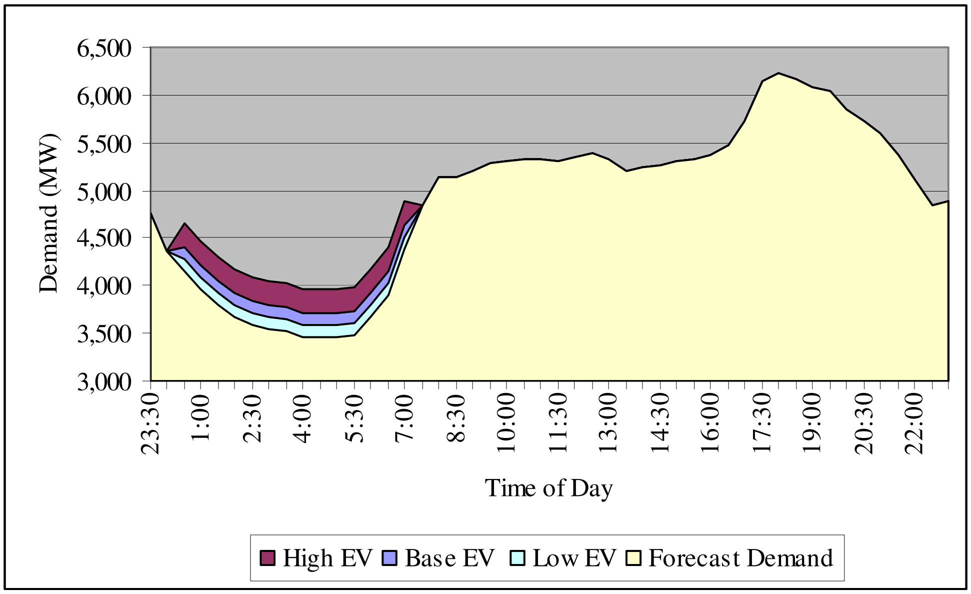


Figure 4-1 Forecast demand for typical week day in 2020 with adjustments for EV load

The impact of this increase in night time load will be significant. A 252MW increase for seven hours every night is an average of 7.7% increase on the business as usual demand figures. This increased load will have a number of benefits.

- Firstly it should allow more wind generate at night. Section 4.1.2 investigates this further.
- Secondly it should allow for easier operation of the electricity system. This premise is examined in Section 4.3.2.

4.1.2 Implications on the Curtailment of Wind Generation

Analysis was undertaken to establish if the introduction of the EV load at night time could potentially result in better utilisation of the wind resource in Ireland. Low night time loads, combined with possible high wind generation at night time mean that variable wind generation would face curtailment in the future. The additional load requirement to charge EVs during night-time periods would result in a reduction in the required curtailment of wind generation resulting in a more effective utilisation of this renewable resource.

It is not presently clear how the Irish electricity system will be operated with large amounts of variable renewable generation, such as wind, connected to the grid. Eirgrid (2009a) are currently undertaking a series of studies regarding the facilitation of renewables in order to develop a better understanding of this, but the findings of this study are not yet available. The topic of EVs will be covered in Eirgrid's study as well as the minimum requirement for synchronous generation on the system with large amounts of renewable generation.

However, in their latest Generation Adequacy Report (GAR) Eirgrid (2009d) show graphically, (see Figure 4-2 below) how storage could save wind generation from curtailment.

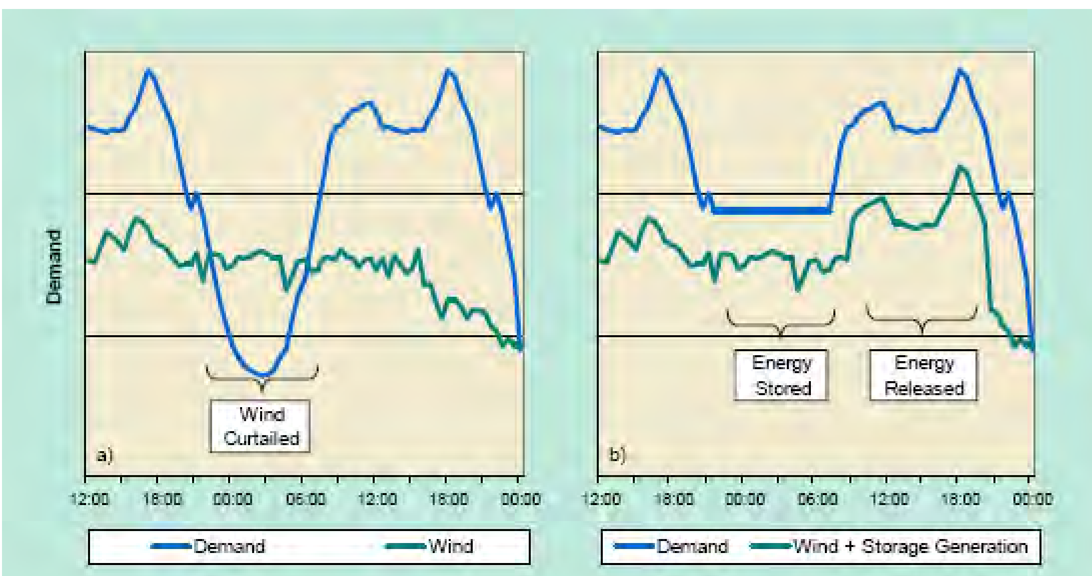


Figure 4-2 The effect storage can have on wind curtailment a) shows a projected period where wind generation exceeds demand, requiring it to be curtailed, b) shows how storage could be used to avoid such curtailment

In the absence of any rules or guidelines for how the Irish system will operate two generic rules have been generated for the purposes of the research presented in this document. These are shown in Table 4-2 below.

Rule 1	Wind energy will, at most, make up 40% of the load at any one time
Rule 2	At least 1,500MW of conventional generation is required on load at any one time for system inertia reasons

Table 4-2 Summary of rules for curtailment analysis

The first ("Rule 1") considered the situation where the wind generation can only make up 40% of the load at any one time. Workstream 2A of the AIGS (2008) used a similar rule, albeit a less stringent limitation, when they carried out an assessment of the suitable generation portfolios in 2020. They assumed that conventional dispatchable generation must make up at least 33% of the load at any one time. The 40% figure in this project was selected to tie in with the government target for renewable generation which is 40% in 2020. Although this target is an annual figure rather than an hourly value, it is reasonable to assume that on average renewable generation would make up 40% of the load at any one time. (Note: The spreadsheet in which the analysis was carried out is available and can be easily adjusted to different percentage figures to give a range of results. For example any outcomes from Eirgrid's study mentioned earlier could be inserted into the spreadsheet to yield a new set of results).

The 2020 load was compared with the ten profiles for wind generation in that year, which were created using historic data (see section 3.1.2). Applying Rule 1, the amount of wind generation in each hour which was greater than 40% of the load, and which would have to be curtailed, was summed for the year. Next the load was adjusted to include the EV night time demand. Again, the amount of wind generation which would have to be curtailed was summed for the year. Both sets of results were compared. In this way, the wind generation "saved" from curtailment was calculated.

Table 4-3 below shows an example of this calculation. The top half of the table shows the load before any EV adjustments have been made. In Hour 1, the wind output is less than 40% of the load, so none of this output has to be restricted. In Hour 2 however the potential wind output of 1,000MW is greater than 40% of the load in that hour. Therefore 160MW of wind output has to be curtailed in that hour. The lower half of the table shows the load adjusted for the EV demand, with an increase of 200MW in each hour. Wind output in Hour 2 now only exceeds the 40% limit by 80MW. Therefore 80MW less wind has to be curtailed.

(MW)	Load with EVs	40% Load	Wind Output	Wind Surplus
Hour 1	2,000	800	700	0
Hour 2	2,100	840	1,000	160
			TOTAL	160
	Load with EVs	40% Load	Wind Output	Wind Surplus
Hour 1	2,200	880	700	0
Hour 2	2,300	920	1,000	80
			TOTAL	80

Table 4-3 Example of Rule 1 curtailment calculation

For "Rule 1" an average figure of 134GWh was calculated as the annual saving of curtailed wind when the base case of EVs was considered. For the low and high EV assumptions (given in Section 3.2.2), the amount of wind generation saved from curtailment was 72GWh and 230GWh per annum respectively.

The second test ("Rule 2") looked at the situation on the system if a certain amount of synchronous generation was required on the system at all times. It is reasonable to assume that for inertia reasons, a minimum level of conventional generation will have to be maintained on the system at any one time. Pöyry (2009) consider this exact requirement for system inertia reasons in their intermittency study. Eirgrid (2009a) are also investigating rules for this exact requirement in their studies. A figure of 1,500MW of conventional generation was used as the minimum value for synchronous generation. This figure roughly represents 300MW of base load renewables, 500MW of coal generation and 700MW of CCGT, which is representative of the ROI generation portfolio in 2020.

Carrying out the same calculations as for “Rule 1” gave a figure of 68GWh of wind generation which would be saved over the year, for the base assumption for EV fleet size. For the low and high EV assumptions the amount of wind generation saved from curtailment per annum was 37GWh and 111GWh respectively.

The above analysis for Rules 1 and 2 was repeated for the high wind case (4,500MW). The results show that for the base case of EVs the GWhs saved under Rules 1 and 2 are on average 242GWh and 168GWh respectively.

All these average results are summarised in Table 4-4 below. The full ten year set of results are given in Appendix C.

	(GWh)	**Base EVs**	**Low EVs**	**High EVs**
Base Wind	Rule 1	134	72	230
	Rule 2	68	37	111
High Wind	Rule 1	242	127	440
	Rule 2	168	89	302

Table 4-4 Annual wind output potentially saved with use of EVs

This analysis shows that the introduction of EV load at night time will save wind generation from being curtailed. The magnitude of the saving is dependent on the size of the EV fleet, the installed wind capacity and the rules of operation used by the system operators. For our base wind and EV assumptions the average energy saved per year would be 101GWh (i.e. (134+68)/2). For the high wind assumption this figure increases to 205GWh. [Note: The above results are based on a controlled night time charging of EVs].

In terms of percentage of total wind generation, these savings are not large. The 101GWh average base case saving represents just 1.13% of the total wind generation with an installed capacity of 3,000MW (i.e. ~8,900GWh). For the high wind case the 205GWh saving is 1.53% of the total wind generation for an installed capacity of 4,500MW (i.e. ~13,400GWh).

The wind saved from curtailment also represents a cost saving to the system. Essentially this is "free" generation which would otherwise have been lost. The AIGS shows average costs of power production ranging from €30/MWh to €43/MWh in 2020. Taking an average of these costs (€36.5/MWh) and applying to the average GWh savings shows an annual saving of between €1.4m and €16.1m depending on size of EV fleet and rules applied. For our base wind and EV case the average saving per annum would be €3.7m (i.e. (4.9+2.5)/2). For the high wind case this figure increases to €7.5m per annum. Full results can be seen in Table 4-5 below.

	€m	Base EVs	Low EVs	High EVs
Base Wind	Rule 1	4.9	2.6	8.4
	Rule 2	2.5	1.4	4.1
High Wind	Rule 1	8.9	4.6	16.1
	Rule 2	6.1	3.3	11.1

Table 4-5 Potentials cost savings (€m) possible with reduction of curtailed wind generation due to introduction of EV load

The beneficiaries of this cost saving will be determined by market rules.

4.1.3 Generation Adequacy Studies

Generation adequacy is a measure of the statistical probability of there being sufficient generation capacity on the system to meet predicted levels of demand. The likelihood of supply shortages and surpluses is calculated by using statistical techniques to determine the probability that demand will exceed supply. The assessment is carried out for every hour in the year being studied and a probability for each hour is calculated. These hourly probabilities are then summed to give an annual expectation of the number of hours in the year that demand would be expected to exceed supply. The annual expectation is known as the Loss of Load Expectation (LOLE). This calculated value is compared against benchmark levels of acceptable risk levels. For ROI the benchmark is eight hours of LOLE per annum. If the LOLE is calculated as being below 8, then the system is said to be in surplus with excess installed generation capacity on the system than is required. Similarly, a LOLE value of greater than 8, means that the system is in deficit, in terms of generation capacity. Eirgrid (2009) give a full description of generation adequacy and the method of calculation. Figure 4-3 below shows a graphical representation of this concept.

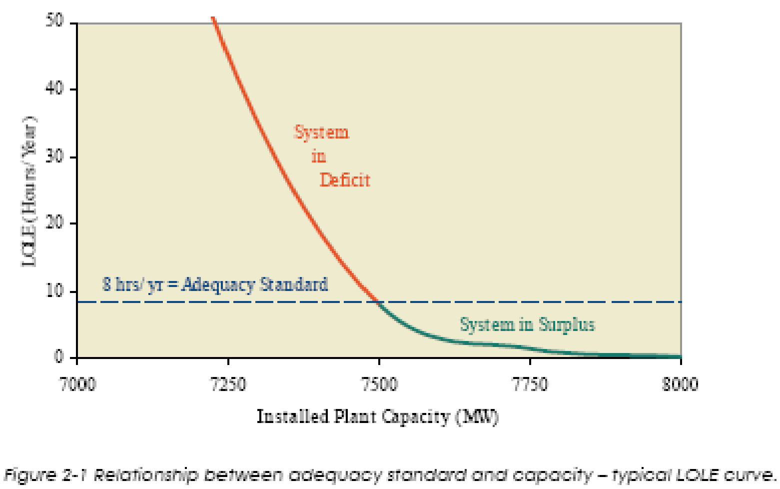


Figure 4-3 Relationship between adequacy standard and capacity – typical LOLE curve (Source: Eirgrid (2008))

Adequacy assessments were carried out on the ROI system for 2020 to see the impact varying levels of wind and EV load would have on the results. The same method that is used by Eirgrid was used in this study. Six adequacy studies were carried out in total and Table 4-6 summarises these.

Studies	Wind Generation (MW)	Electrical Vehicle Numbers
1	Base – 3,000	0
2	Base – 3,000	Base – 250,000
3	Base – 3,000	High – 500,000
4	High – 4,500	0
5	High – 4,500	Base – 250,000
6	High – 4,500	High – 500,000

Table 4-6 Adequacy study summary

The adequacy tests were carried out using the Ad Cal tool, which was provided for use in this study by Anthony Harpur. A description of the software is given in Appendix G.

The results of the six studies are shown in Table 4-7 and show that the inclusion of the EV load does not alter the LOLE in either the base or high wind cases.

In the base wind case the system has a LOLE of 6.6 hours and a surplus of 42MW of generation capacity when no EV load is considered. These figures remain the same when the EV load is introduced. Even when the amount of EVs is increased to half a million, (case 3), the LOLE remains the same. This shows that the adequacy assessment of the system does not vary as a result of introducing the EV load. It is clear from this that no new generation would be required on the system to meet the new load.

Studies	Annual LOLE (Hours)	8 Hour LOLE (MW)
1	6.60	+ 42
2	6.60	+ 42
3	6.60	+ 42
4	4.79	+ 117
5	4.79	+ 117
6	4.79	+ 117

Table 4-7 Adequacy study results

These studies do not show definitively however that the additional night time load allows for more wind generation on the system. However, some conclusions can be drawn from the adequacy studies. These are:

- The inclusion of the EV night time load does not have any impact on the system adequacy
- No new generation is required on the system to serve the EV load
- The inclusion of the EV night time load ensures better use of generation resources
- Random charging would decrease the surplus and increase the annual LOLE

4.2 Ancillary Services & Back Up Provision

The following subsections examine whether EVs could be used for the provision of operating reserve and back-up generation, the need for both of which will increase as the levels of intermittent wind generation on the system also increase.

4.2.1 EVs as Providers of Reserve

Due to the intermittent nature of wind generation, the requirement for provision of Ancillary Services (AS) on the grid, such as operating spinning reserves or frequency regulation, will rise as the level of wind generation on the system rises. Eirgrid (2009a) are carrying out investigations into the increased flexibility requirements which will be required on the system in the future as a result of increased uncertainty and variability in generation such as wind. They are investigating requirements for regulation reserve, primary operating reserve, secondary operating reserve, tertiary operating reserve, replacement reserve, substitute reserve and total ramping capability. (Note: definitions of these AS can be found in Appendix E). Workstream 2B of the AIGS (2008) found that nearly all the replacement reserve was provided by offline OCGT. EVs may form part of the solution for these new requirements, given their ability for quick response.

To understand the increased need for provision of such AS it is best to look at how much wind generation is likely to fluctuate. In this study 1-Hour and 4-Hour changes in wind output are considered. (Note: 1-Hour is the smallest granularity of data available for this study). The graphs below show these 1-Hour and 4-Hour MW change in wind output for a typical year for the base and high wind cases (i.e. 3,000MW and 4,500MW of wind installed in 2020 respectively).

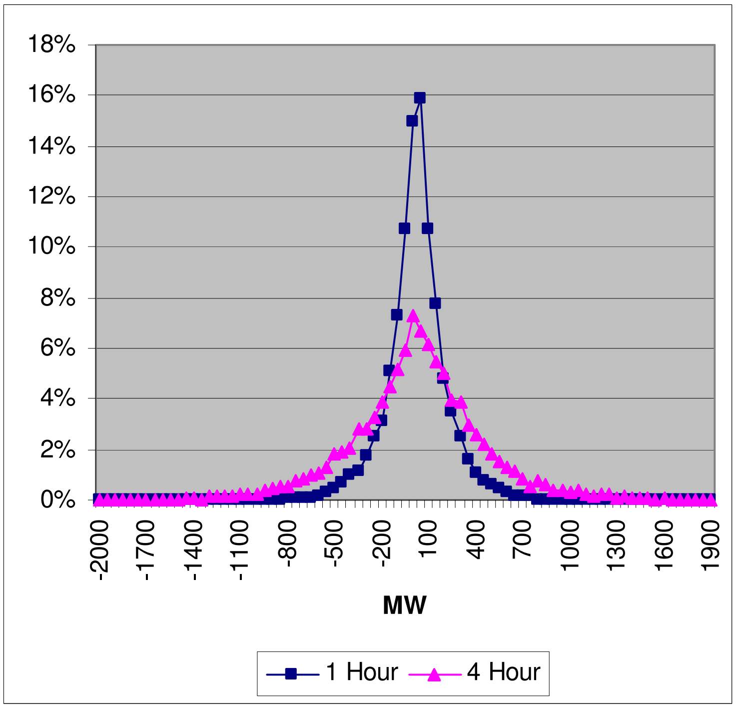


Figure 4-4 Distribution analysis of 1-Hourly & 4-Hourly wind output variations for base wind assumption

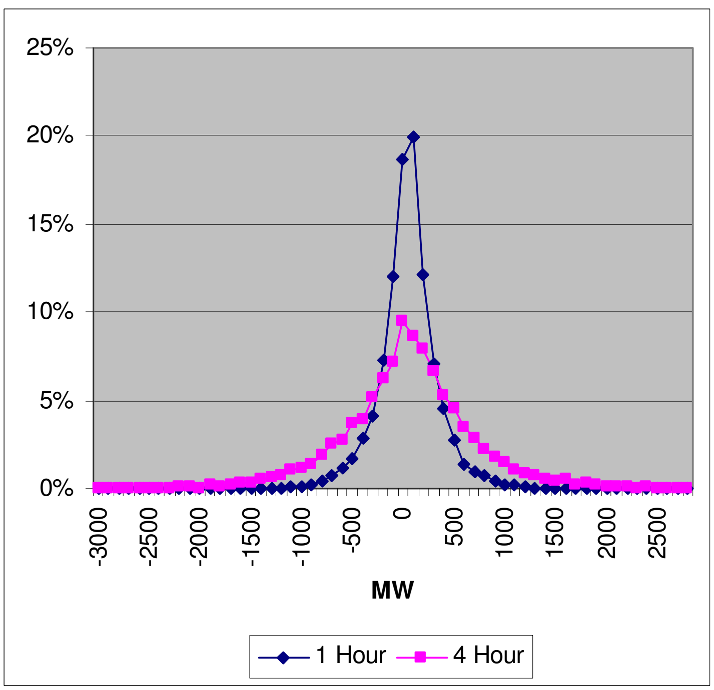


Figure 4-5 Distribution analysis of 1-Hourly & 4-Hourly wind output variations for high wind assumption

These graphs show that for the base case of installed wind capacity (see 3.1.1), the output from wind can vary by in excess of ±1,000MW in a one hour period, and by ±1,900MW in a four hour period. For the high wind case, these figures increase to ±1,600MW in a one hour period, and ±2,900MW in a four hour period. (Note: These graphs are based on a single years wind profile. The complete set of results for the ten years can be found in Appendix D). It is clear that the requirement on other sources of load and demand to meet this fluctuation will be substantial.

Analysis was carried out to compare the 1-Hour and 4-Hour reserve requirements with the potential capability of EVs to provide AS. (This analysis was compiled using assumptions on installed wind capacity from 3.1.1, the varying EV fleet size assumptions from 3.2.2 and base EV charge rate from 3.2.4). The results of this analysis are shown in Table 4-8 below.

(MW)	Base Wind	High Wind
Max 1-Hour Ramping Requirement	1,000	1,600
Max 4-Hour Ramping Requirement	1,900	2,900
Base EVs Max Ramping Capability	750	
Low EVs Max Ramping Capability	375	
High EVs Max Ramping Capability	1,500	

Table 4-8 Ramping requirements of electricity system as a result of additional wind generation on the system compared with ramping capability of EV fleet

The EV ramping capability ranged from 375MW to 1,500MW, depending on fleet size. For the Base EV case the max ramping capability of the EV fleet was calculated at 750MW (i.e. 250,000 x 3kW). As can be seen from the comparison above, this is a sizeable portion of the maximum 1-Hour and 4-Hour requirements of the fluctuating wind generation. If both the base case for EV fleet size, and base case for wind generation are assumed, (highlighted in yellow in Table 4-8 above), it is possible that 75% of the maximum 1-Hour ramping capability required, as a result of the large amounts of wind generation on the system, could be met be the ramping capability of the EVs. Although this figure drops to 40% for the 4-Hour category, (i.e. 750/1900), it is more likely that the shorter time frame capability will be of greatest importance as other conventional generation can be ramped up and down to meet the fluctuations, given more notice.

The above table assumes a standard charging / decharging rate of 3kW for the EVs. Two further charging rates of 25kW and 120kW are assessed in Table 4-9 below. The "Fast" and "Emergency" rates, taken from ESB (2009), could potentially result in EV ramping capability far in excess of the requirement to meet the variation due to wind.

	No. of EVs	Charge / Decharge Rate		
		Standard (3kW)	Emergency (25kW)	Fast (120kW)
		MW Capability		
Base	250,000	750	6,250	30,000
Low	125,000	375	3,125	15,000
High	500,000	1,500	12,500	60,000

Table 4-9 Ramping capability of EV fleet for different levels of EV penetration and different charging rates

While the above analysis has focused on the extremes of the fluctuations in wind output, the vast majority of hourly changes are far smaller as can be seen in the earlier distribution curves (Figure 4-4 & Figure 4-5).

Table 4-10 below shows that for the base wind case, over 80% of the 1-Hourly fluctuations are less than ±200MW. To meet this requirement approximately 67,000 EVs at the standard rate of 3kW would be required.

	Base Wind (3000MW)		High Wind (4,500MW)	
	1 Hour	4 Hour	1 Hour	4 Hour
±100MW	59.58%	31.29%	50.67%	25.33%
±200MW	80.31%	50.09%	70.16%	39.52%
±500MW	97.84%	82.08%	93.00%	68.75%
±1000MW	99.97%	96.90%	99.39%	90.25%

Table 4-10 Tabular distribution analysis of 1-Hourly & 4-Hourly wind output variations for base and high wind assumptions

So while the EVs may not be able to solely cover the extreme fluctuations caused by large fluctuations in wind output, as seen in Table 4-8, it is likely that the fleet resource could be used as part of the solution in the management for the majority of smaller fluctuations.

However, while these figures show that the scale of the EV fleet resource means that it could potentially be used for the provision of AS to the electricity system, a number of items have not been taken into consideration:

i. The figures above have assumed that the entire EV fleet are available at any one time
ii. It has also been assumed that all EVs are fully charged
iii. Intrinsic in the calculations is the assumption that the infrastructure which would be required so as EVs could be used as a controllable flexible load and / or demand source, would be available.
iv. Finally it is assumed that all EV owners are willing to provide the service if required. Rates and tariffs would have to incentivise this behaviour

If the ramping capability of the EV fleet is adjusted to take point (i) above into consideration then more realistic capability figures are calculated. These are shown in Table 4-11 below. These calculations have assumed that EVs on average are away from base 7 hours per day. The fleet size availability will shrink by ~33%.

	No. of EVs Available	Charge / Decharge Rate		
		Standard (3kW)	Emergency (25kW)	Fast (120kW)
		MW Capability		
Base	166,667	500	4,167	20,000
Low	83,333	250	2,083	10,000
High	333,333	1,000	8,333	40,000

Table 4-11 Realistic ramping capability of EV fleet for different levels of EV penetration and different charging rates

However, as was seen earlier in Table 4-10 over 97% of 1-Hourly fluctuations for the base wind case are less than 500MW, which matches the capability of the base EV fleet, even taking into account the fact that over one third of EVs will be away from base, and unavailable for the provision of AS at any one time. Therefore it is still a reasonable conclusion that EVs could potentially play a significant role in the provision of AS.

4.2.2 EVs as Back Up Generation

As was seen in Section 2.2 there is potential for EVs to provide back-up generation for wind capacity. During periods of low wind output EVs, via V2G technology, could be employed as a replacement source of generation for wind, as an alternative to building excess conventional generation at a high cost to cover these infrequent events.

Using the same method employed by Kempton et al. (2006) a comparison was performed of the potential scale of the resource available from EVs via V2G compared with the average national load in 2020. The results of this analysis are shown in Table 4-12 below.

No. of EVs	V2G @ 15kW from all EVs (MW)	% of Average Load
125,000	1,875	44%
250,000	3,750	87%
500,000	7,500	175%

Table 4-12 The V2G potential in ROI in 2020

The above calculation shows that the V2G power potential is very large. Assuming base case EV fleet size and a charging rate of 15kW, would mean that EV resource could potentially supply 87% (as shown highlighted in yellow in Table 4-12 above) of the average instantaneous load in 2020. However, this is a relatively simple calculation and does not take into consideration a number of items such as:

- The availability of the EVs to provide power i.e. how many and how often they are away from base
- The energy storage capability of EVs and amount of time power could be drawn
- A lower grid connection per car (Lund et al (2008) assume 10kW)
- The actual requirement for back up generation

If the requirement for back up generation and EV resource are assessed from a stored energy rather than an instantaneous power perspective the potential for provision of back-up generation does not seem as large as was portrayed in Table 4-12 above. A more comprehensive calculation was therefore carried out.

Firstly the back-up generation requirement was considered by analysing the ten generated wind profiles to assess them for the frequency and duration of low load events. Kempton et al (2006) define a low load event where the output of wind generators is at less than 20% of rated. Firstly, the low load events were quantified. For the ten generated profiles it was seen that the longest period of low output was 385 hours, or sixteen days. This means that potentially the EV resource in ROI would be required to provide backup for this period to the equivalent output of the wind generators.

Figure 4-6 below shows the frequency and duration of low load events over the ten year period studied. As expected most of the low load events are short in duration. This is seen more clearly in Table 4-13 where it shows that over 56% of these events are less than six hours in duration.

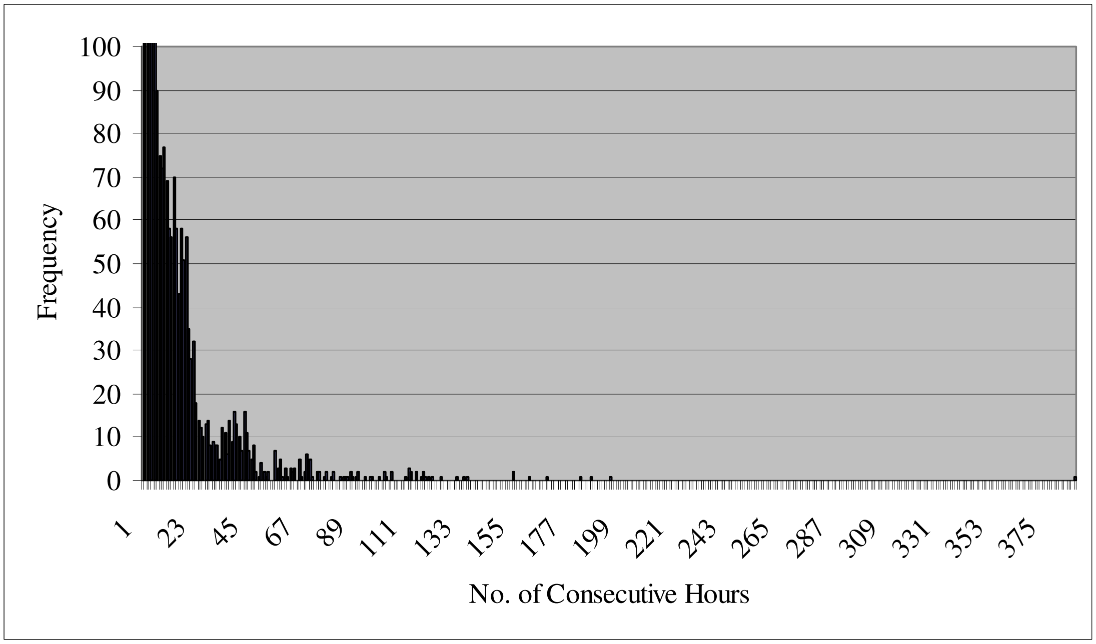


Figure 4-6 Consecutive hours of low load wind over a ten year period

Hours	% of Events
<1	26.1%
<2	37.4%
<3	44.4%
<4	49.4%
<5	53.3%
<6	56.5%

Table 4-13 Most frequent periods of low load wind output

However, replacement generation is required for the worst case scenario therefore the extreme and rare events need to be considered. Table 4-14 lists the occurrence of the longest periods of low output. There are 13 events over the ten year period greater than five days (or 120 hours) in duration. In other words, on average once a year you can expect the output from wind generators to be below 20% of rated continuously for 5 days. Replacement generation would be required to meet this shortfall.

	No. of Low Load Events
> 1 Day	347
> 2 Days	113
> 3 Days	55
> 4 Days	32
> 5 Days	13
> 6 Days	8
> 7 Days	4
> 8 Days	2
> 16 Days	1

Table 4-14 Longest periods of low load wind outputs over ten year period

Assuming that the 16 day period is the worst case scenario, Table 4-15 shows what the corresponding maximum back up generation would be to cover this eventuality. If there was 3,000MW of wind installed on the system approximately 25.2GWh of generation would be required via V2G per day for the 16 day period, assuming that on average wind is generating at 35% of its rated capacity (i.e. 3,000MW x 35% x 24hours). This figure increases to 37.8GWh for the high wind case of 4,500MW of installed capacity.

	GWh Requirement Base Wind (3,000MW)	GWh Requirement High Wind (4,500MW)
Daily Requirement	25.2	37.8
16 Day Total	403.2	604.8

Table 4-15 Back-up generation required to meet longest low load wind event

However, Table 4-15 does not take into consideration that EV generation as a back up to wind would mainly be required over peak hours, (where peak hours are the four hours from 4pm to 7pm inclusive), when capacity margin is at its tightest. At other times during the day, a shortfall in wind could be met by conventional generation which is not already operating at maximum capacity. The figures in Table 4-15 were therefore revised down to take this into consideration.

The ten years of wind profile data was analysed to assess the contribution of wind generation over the peak hours. The average wind output was found to be 37.5% over this period, compared with 34.0% for the twenty-four hour average. The maximum and minimum wind output over the peak periods were 0.2% and 98.9% of rated respectively. Table 4-16 below shows how this information translates to the contribution of wind generation over peak hours.

	Base Wind	High Wind
Max	44.9%	67.4%
Min	0.1%	0.2%
Avg	17.1%	25.6%

Table 4-16 Percentage of peak demand met by wind in 2020

This means that EVs could be required to provide this amount of back-up generation. Using the maximum figures means that EVs would be required to provide the instantaneous and cumulative daily totals shown in Table 4-17 below. This gives a realistic requirement for the scale of EV generation which would be required to provide back-up to wind generation.

	Base Wind	High Wind
MW	2,967	4,451
4-Hour GWh	11.87	17.80

Table 4-17 EV requirement to cover peak hours back up generation

Next the capability of the EV fleet was calculated to compare with the requirement. Table 4-18 below shows the maximum value of the energy stored in the EV fleet in 2020. These figures assume that all EVs are fully charged. The figure varies from 1.375GWh to 13.5GWh depending on the no. of EVs and the assumption on the storage per vehicle. Using the base case assumptions yields a figure of 5GWh.

	Energy Storage per EV	Total Energy Storage		
		Low EV Case	Base EV Case	High EV Case
	kWh	GWh		
Low	11	1.375	2.75	5.5
Base	20	2.5	5	10
High	27	3.375	6.75	13.5

Table 4-18 Potential total energy storage capability of EV fleet

However, realistically not all vehicles are going to be plugged in and available at any one time, nor are all going to be fully charged. Kempton et al. (2001) assume that between 92% and 96.3% of EVs are available for V2G at any one time.

Without even taking these factors into consideration, it can be seen that the scale of the EV resource in terms of stored capacity is far less than what would be required in terms of back up generation for wind. In Table 4-17 above we saw that for the base wind case, 11.87GWh of energy per day would be required if the 3,000MW of wind generation was unavailable over the 4-Hour peak period. Comparing this with the potential capability of the EV fleet seen in Table 4-18 shows that only under the high EV case (i.e. fleet size of 500,000), combined with the high energy storage capability (i.e. 27kWh per EV) will the EV resource be able to provide this cover.

Table 4-18 assumes that all EVs are fully charged and all plugged in and available to be used. However, as seen in 3.2.3 this is not the case. If we assume that EVs on average are away from base on 7 hours per day, then the fleet size availability will shrink by ~33%. Instead of 250,000 EVs being available (in the base case) only 177,000 will actually be plugged in at their base. Similarly if we assume the average distance travelled per day is 47km, (which is a third of the assumed driving range capability figure from Table 3-7), and that the corresponding amount of energy is dissipated from the EVs, then the total energy storage capability of the EV fleet changes to Table 4-19 below.

	Energy Storage per EV	Total Energy Storage		
		Low EV Case	Base EV Case	High EV Case
	kWh	GWh		
Low	7.3	0.6	1.3	2.6
Base	13.3	1.2	2.4	4.7
High	18.0	1.6	3.2	6.4

Table 4-19 Realistic total energy storage capability of EV fleet

This shows that more realistic figures for the total energy stored in the EV fleet available at any one time for back up generation are less than half the potential figures seen in Table 4-18. Now comparing the requirements from Table 4-17 with this realistic capability shows that under no scenario would the requirement for back up generation to wind be met by EVs. Comparing the base case capability from Table 4-19 with both the base and high back up generation requirements (from Table 4-17) yields proportions of

20% and 13% of the requirements being met (i.e 2.4GWh / 11.87GWh and 2.4GWh/17.8GWh).

4.3 Other Impacts

The following subsections consider other effects the presence of EVs may cause. These are the impact on carbon emissions and any other significant benefits to the operation of the electricity system.

4.3.1 Carbon Emission Savings

A calculation was carried out to estimate the potential annual CO2 saving the introduction of EVs could bring with it. Using the assumptions outlined in Section 3.4 it was estimated that between 213 and 849 kTonnes could be saved annually as a result of replacing conventional cars with EVs. Table 4-20 below shows the details of this calculation.

	No. of EVs	Annual Emissions (BAU)	Additional Electrical Load	CO2 Emissions from Additional Elec. Load	CO2 Saving
		kTonnes	GWh	kTonnes	kTonnes
Low	125,000	349	322	109	213
Base	250,000	697	643	219	424
High	500,000	1,394	1,287	438	849

Table 4-20 Potential CO2 savings with introduction of EVs

4.3.2 Easier Management of Electricity System

Controllable demand makes the management of the electricity system easier for the System Operator in ROI. Currently, Eirgrid, make use of various demand side response schemes including Winter Peak Demand Reduction Scheme (WPDRS), Powersave and Short Term Active Response (STAR). A controllable EV demand could also be used to the advantage of the management of the grid. Some of the benefits already seen include the provision of reserve for the fluctuating wind generation portfolio through the use of V2G technology. However there are other benefits to the system operator which would not rely on this sophisticated technology.

An increased night time load will be beneficial to the system as it could avoid the requirement for more conventional generation to 2-shift, or turn off at night. Low night time valleys, relative to high day time peaks mean that considerably more conventional generation is needed on the system in the day time compared with night. Therefore much of this generation is required to turn off each night time and ramp up again the next morning. The disadvantages of this are two fold.

Firstly, there is a risk to the system that the units will fail to start. If this happens the system is at risk of having to load shed. Fast responding expensive generation would have to be started to cope with such failed starts, increasing the overall cost of generation to the system.

The second disadvantage to having much conventional generation 2-shifting is the inefficiency associated with this cycling. There is a cost associated with each start up of a generator. There is also an impact on the wear and tear of the plant, with maintenance costs increasing with increased cycling.

An additional 252MW of EV load at night time, (as calculated in 4.1.1), could avoid the cycling of a 390MW CCGT and 280MW conventional generator each night, (assuming that minimum loads for such plant is as per Eirgrid (2009c), i.e. 50% & 35% of rated capacity for CCGT and conventional generators respectively).

To look at the financial impact of these avoided starts, the average start costs of equivalent CCGT and coal plants were examined, as per the daily published bids of generators into the AIM on December 9th 2009. The equivalent start cost of the CCGT and coal units were €62k and €68k respectively. This means that potentially €130k could be saved every night these two units do not have to 2-shift due to the additional night time load of EVs. Table 4-21 below shows these calculations. If you assume this cost is avoided every night, then the annual saving is greater than €47m.

	Max Generation	Min Generation	Min Generation	Start Cost*	Max Annual Start Cost
	MW	%	MW	€	€
Conventional Generator	280	35%	98	62,000	22,620,000
CCGT	390	50%	195	68,000	24,820,000
		Total	293	130,000	47,450,000

* Start costs as per SEMO (2009) (www.allislandmarket.com/marketpublications/dailypublications)

Table 4-21 Start Costs of 2-Shifting Plant

5 Conclusions & Future Work

A summary of the project and the main findings are presented in this Chapter. A critical analysis of the methodology used is also given along with suggestions for future research work.

5.1 Summary of Project

A review of literature, and also the Irish context, relating to EVs and their use to complement intermittent variable renewable generation, such as wind, on electricity systems was undertaken. From this, research questions relating specifically to the Irish context were raised. In order to investigate these questions, the year 2020 was taken as the focus point and assumptions in relation to wind generation, EV fleet size and characteristics, electricity demand etc. were developed for that year. A data set was also established for that year and analysis work was then carried out on it. It was concluded among other things that the increased night time demand which EVs cause, could save wind generation from being curtailed and thus a cost saving resulting. EVs were also seen to have potential to play a role in the provision of ancillary services, such as reserve, which rise as the level of intermittent variable generation on an electricity system increases. However, EVs as a source of back-up to wind generation in times of low wind speeds were not found to be viable.

5.2 Key Outcomes & Findings

The key findings of this project are:

- An EV fleet size of 250,000 could raise the night time load in ROI by ~252MW
- The introduction of EV load at night time will save wind generation from being curtailed. The magnitude of the saving is dependent on the size of the EV fleet, the installed wind generation capacity and the rules of operation used by the system operators. For the base wind and EV assumptions the average energy saved per year would be 101GWh and for the high wind assumption this figure increases to 205GWh per annum.

- A financial saving can be calculated for the wind generation saved from curtailment. Assuming an average cost of €36.5/MWh for power, gives a total saving of €3.7m p.a. for the base case, and €7.5m p.a. for the high wind case.
- The inclusion of the EV night time load does not have any impact on the system in terms of generation adequacy and no new generation would be required on the system to serve this EV load
- For an installed capacity of 3,000MW of wind generation in 2020, the output can expected to fluctuate between ±1,000MW in a 1-Hour period, and between ±1,900MW for a 4-Hour interval. If the installed capacity of wind is 4,500MW this output variations increase to ±1,600MW and ±2,900MW for 1-Hour and 4-Hour intervals respectively.
- The ramping capability of the base case EV fleet, assuming a standard charging rate is 750MW. This means that 75% of the 1-Hour wind fluctuations could be met by the base case EV fleet.
- If higher charging rates are assumed for EVs, e.g. 25kW or 120kW, then the EV fleet ramping capability would be far in excess of the requirement to meet fluctuating wind outputs.
- Over 97% of the 1-Hour wind output fluctuations (for base wind case) are within a range of ±500MW which is within the capability of the base case EV fleet, even taking into account that over a third of EVs would not be available for the provision of reserve at any one time.
- On average it can be expected that the longest consecutive period of low wind generation per year is 5 days. However, over 56% of low load events are less than 6 hours.
- Simplistic calculations show that the potential for the use of EVs as back-up generation to wind is high, with 87% of average load in 2020 potentially being met with the EV fleet resource. However, more detailed calculations show that this figure is unrealistic.

- EV back up generation to wind would mainly be required over peak periods during the day. The daily requirement to provide back up for 3,000MW of wind in 2020 would be approximately 11.87GWh. For the high wind scenario, (i.e. 4,500MW), 17.8GWh of back up would be required per day.
- The capability of the EV fleet to meet the back up generation requirement to wind depends on many things including the energy storage capability of the EVs, the size of the fleet, the average distance travelled per day per EV and the amount of time the EVs are plugged in and available to provide power.
- In all the scenarios considered, the EV fleet would be unable to meet the daily back up requirement for wind generation. The base case scenario yields a capability of the EV fleet in 2020 to provide 2.4GWh of power per day. This makes up 20% and 13% of the base and high wind generation back up requirements respectively.
- An EV fleet size of 250,000 could avoid annual CO2 emissions of 424ktonnes
- An EV fleet size of 250,000 could potentially save over €47m in avoided start costs of conventional generators due to the increased night time load

5.3 Critical Analysis of Methodology

A large part of this project involved the collation of a set of assumptions for 2020 (as laid out in Chapter 3). This was done by reviewing various sources of information and selecting what was estimated to be the most appropriate. An alternative method would have been to source all information, insofar as possible, from a single published source. This could have allowed for easier comparison with other bodies of work with the analysis contained in this report.

"Rule 1", used in Section 4.1.2 to analysis the impact of the charging of EV batteries at night on levels of wind generation curtailment, used a figure of 40% as the limit to which wind generation could make up of the load at anyone time. This figure was chosen to tie in with the Government of target of 40% renewable generation in 2020. However, by applying this rule, the government 40% target would never be achieved in the night time hours. A larger percentage figure would have been more appropriate.

The wind data used in this project had a granularity of one hour. This time frame dictated the period that could be used in examining changes in wind generation output in this project. Much of the AS analysis carried out in Section 4.2 used this data. However, it may be that the minute by minute and second by second variations in wind generation output are more significant when assessing the use of EVs as a method to provide AS. This is because more conventional generation could play a greater role when the time periods are extended.

5.4 Suggestions for Future Work

The points below propose some areas where further work could be carried out to complement this project.

- An economic dispatch model could be run for the 2020 situation with and without the EV demand. Varying amounts of wind generation could be included. Outputs of this study could be used to analyse the following:
    - The impact EV demand has on wind curtailment
    - The total system costs with and without EV demand
    - The avoided start costs of conventional generators with the inclusion of EV demand
- Historic wind data with smaller granularity could be sourced. This would allow for analysis for the requirement of the provision of spinning reserves to meet the second by second and minute by minute variations in wind generation output. EV capability could then be compared to this.
- The viability of EVs in Ireland could be studied. Consumer appetite could be assessed as well as a review of the infrastructure that would need to be put in place to facilitate widespread usage of EVs. A cost associated with this could then be calculated. The further infrastructure and costs associated with V2G

technology could also be analysed and compared to benefits associated with their provision.

- Undertake a detailed review of EV technology so that more up to date and accurate figures could be ascertained for such values as storage capacity per vehicle.
- Survey of vehicle usage, especially fleets such as taxis and buses, in Ireland could be undertaken to give more meaningful data to EV availability for back up generation to wind.

Appendix A. References

Central Statistics Office (CSO) (2008) *Transport 2007,* CSO, Dublin

Commission for Energy Regulation (CER) & Northern Ireland Authority Utility Regulation (NIAUR) (2009) *Impact of High Levels of Wind Penetration in 2020 on the Single Electricity Market*

Department of Communications, Energy & Natural Resources (DCENR) (2008) *Transforming transport will help economy to recover – 250,000 electric vehicles on the road by 2020,* DCENR, Dublin

Department of Communications, Energy & Natural Resources (DCENR) (2009) *Historic deal will transform Irish transport Electric vehicles moving from vision to reality – Minister Ryan,* DCENR, Dublin

Department of Communications, Energy and Natural Resources (DCENR) & Department of Enterprise, Trade and Investment (DETI) (2008) *All Island Grid Study,* Dublin

Divya, K & Østergaard, J (2008) Battery energy storage technology for power systems – An overview. *Electric Power Systems Research,* December, Vol. 79 511-520

Eirgrid (2008a) *Generation Adequacy Report 2009-2015,* Dublin

Eirgrid (2008b) *Grid 25 – A strategy for the development of Ireland's electricity grid for a sustainable and competitive future,* Eirgrid, Dublin

Eirgrid (2009a) *TSO Facilitation of Renewables Studies,* Eirgrid

Eirgrid (2009b) *TSO Facilitation of Renewables Studies Update,* Eirgrid

Eirgrid (2009c) *Grid Code V3.4,* Eirgrid

Eirgrid (2009d) *Generation Adequacy Report 2010-2016,* Dublin

Electricity Supply Board (ESB) (2009) *Infrastructure Issues for Electric Vehicle Deployment in Ireland,* SEI Electric Vehicle and Sustainable Transport Conference, Dublin

General Motors (GM) (2009) *Electrification of the Automobile,* SEI Electric Vehicle and Sustainable Transport Conference, Dublin

Gibson, E (2009) Electric car fleet could run on wind power. *New Zealand Herald,* 24th March.

Harpur, A (2009) AdCal Generation Adequacy Calculation. Version 2.02. User Manual

Kempton, W & Kubo, T (1999) Electric-drive vehicles for peak power in Japan. *Energy Policy,* 28 9-18

Kempton, W, Tomic, J, Letendre, S, Brooks, A & Lipman T (2001) Vehicle-to-Grid Power: Battery, Hybrid, and Fuel Cell Vehicles as Resources for Distributed Electric Power in California, *California Environmental Protection Agency and Los Angeles Department of Water and Power, Electric Transportation Program*

Kempton, W & Tomić, J (2004a) Vehicle-to-grid implementation: From stabilising the grid to supporting large-scale renewable energy. *Journal of Power Sources,* 144 280-294

Kempton, W & Tomić, J (2004b) Vehicle-to-grid fundamentals: Calculating capacity and net revenue. *Journal of Power Sources,* 144 268-279

Kempton, W & Dhanju, A (2006) Electric Vehicles with V2G. Storage for Large-Scale Wind Power. *Windtech International*

Letendre, S & Kempton, W (2002) The V2G Concept: A New Model for Power? Connecting utility infrastructure and automobiles. *Public Utilities Fortnightly,* February 15th, 16-26

Lund, H & Kempton, W (2008) Integration of renewable energy into the transport and electricity sectors through V2G. *Energy Policy,* July, 3578-3587

Marano, V & Rizzoni, G (2008) Energy and Economic Evaluation of PHEVs and their integration with Renewable Energy Sources and the Power Grid. *IEEE Conference on Vehicular Electronics and Safety,* September 22-24, 84-89

Mitsubishi Ireland (2009) *iMiEV and Ireland's Electric Vehicle Future,* SEI Electric Vehicle and Sustainable Transport Conference, Dublin

National Renewable Energy Laboratory (NREL) (2006a) *A Preliminary Assessment of Plug-In Electric Vehicles on Wind Energy Markets,* NREL, USA.

National Renewable Energy Laboratory (NREL) (2006b) *An Evaluation of Utility System Impacts and Benefits of Optimally Dispatched Plug-In Hybrid Electric Vehicles,* NREL, USA.

Pina, A, Ioakimidis, S and Ferrão, P (2008) Introduction of electric vehicles in an island as a driver to increase renewable energy penetration. *ICSET,* 1108-1113

Pöyry Energy Consulting (Pöyry) (2009) *Implications of Intermittency – A multi-client study,* Pöyry, London.

Shortt, A and O'Malley, M (2009) Impact of optimal charging of electric vehicles on future generation portfolios. *IEEE/IAS Sustainable Alternative Energy Conference,* (Currently being peer reviewed)

Sovacool, B & Harris, R (2008) Beyond batteries: an examination of the benefits and barriers to plug-in hybrid electric vehicles (PHEVs) and a vehicle-to-grid (V2G) transition. *Energy Policy,* December, 1095-1103

System Operator for Northern Ireland (SONI) (2008) *Seven Year Generation Capacity Statement 2009-2015*

Sustainable Energy Ireland (SEI) (2007a) *Energy in Ireland 1990 - 2006*, SEI, Dublin

Sustainable Energy Ireland (SEI) (2007b) *Energy in Transport,* SEI, Dublin

Sustainable Energy Ireland (SEI) (2007c) *Hybrid Electric and Battery Electric Vehicles. Technology, Costs and Benefits,* SEI, Dublin

Sustainable Energy Ireland (SEI) (2007d) *Buyers' Guide for Electric and Hybrid Vehicles,* SEI, Dublin

Sustainable Energy Ireland (SEI) (2009a) *Media Information: Electric Vehicle and Sustainable Transport Conference Opens in Dublin,* SEI, Dublin

Sustainable Energy Ireland (SEI) (2009b) *Renewable Energy and Transport Developments,* SEI Electric Vehicle and Sustainable Transport Conference, Dublin

Tomić, J & Kempton, W (2007) Using fleets of electric-drive vehicles for grid support. *Journal of Power Sources,* 168 459-468

Turton, H & Moura, F (2008) Vehicle-to-grid systems for sustainable development: An integrated energy analysis. *Technological Forecasting & Social Change,* 75 1091-1108

Appendix B. Wind Data

		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Bellmullet	Avg	47%	43%	43%	44%	52%	42%	46%	43%	49%	45%
	Max	99%	99%	99%	99%	99%	99%	99%	99%	99%	99%
	Min	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Std Dev	36%	36%	35%	35%	37%	36%	37%	37%	38%	37%
Dublin	Avg	30%	26%	29%	29%	33%	28%	29%	28%	33%	24%
	Max	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Min	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Std Dev	32%	32%	32%	32%	34%	32%	33%	33%	37%	32%
Malin Head	Avg	57%	51%	56%	58%	60%	53%	57%	51%	59%	56%
	Max	99%	99%	99%	99%	99%	99%	99%	99%	99%	99%
	Min	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Std Dev	36%	38%	37%	36%	37%	38%	37%	38%	38%	37%
Rosslare	Avg	24%	26%	36%	33%	37%	33%	36%	34%	35%	34%
	Max	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

	Min	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Std Dev	30%	32%	36%	34%	34%	34%	35%	34%	33%	34%
Shannon	Avg	22%	21%	21%	22%	25%	23%	25%	24%	22%	19%
	Max	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Min	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Std Dev	28%	28%	28%	28%	30%	29%	31%	30%	29%	25%
Compiled Profile	Avg	33%	31%	33%	34%	38%	33%	36%	34%	36%	32%
	min	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	max	100%	100%	100%	99%	100%	100%	100%	100%	100%	100%
	stddev	25%	26%	25%	25%	26%	26%	27%	27%	26%	25%

Appendix C. Curtailment Study Results

		Assumption 1				
	Wind Profile	GWh Lost	GWh Saved by EVs (Base)	% Saved	GWh Saved by EVs (High)	GWh Saved by EVs (Low)
1989	32.4%	698	123	18%	211	67
1990	35.9%	981	169	17%	295	91
1991	33.6%	1,013	135	13%	236	72
1992	35.7%	1,090	150	14%	257	82
1993	33.1%	842	131	16%	231	70
1994	38.2%	1,135	165	15%	287	88
1995	33.8%	747	119	16%	201	65
1996	33.3%	821	122	15%	203	67
1997	30.9%	821	116	14%	201	61
1998	33.2%	744	108	15%	182	58
Average	34.0%	889	134	15%	230	72

Appendix D. Ten Year Ramping Requirements

	Base Wind (3,000MW)				High Wind (4,500MW)			
	1 Hour		4 Hour		1 Hour		4 Hour	
	Max	Min	Max	Min	Max	Min	Max	Min
1998	1,332	-1,066	2,233	-1,922	1,998	-1,599	3,350	-2,882
1997	1,380	-1,131	2,010	-2,086	2,071	-1,697	3,015	-3,129
1996	1,135	-1,393	2,056	-1,799	1,703	-2,090	3,083	-2,698
1995	1,098	-1,056	1,831	-1,942	1,647	-1,583	2,746	-2,913
1994	1,103	-1,114	2,228	-2,274	1,655	-1,671	3,342	-3,411
1993	1,412	-1,073	1,867	-1,982	2,119	-1,609	2,800	-2,973
1992	1,020	-1,197	2,188	-1,910	1,530	-1,795	3,282	-2,865
1991	1,126	-1,350	1,958	-2,185	1,689	-2,024	2,937	-3,277
1990	966	-997	1,827	-1,764	1,449	-1,496	2,740	-2,647
1989	1,032	-1,146	2,336	-1,944	1,547	-1,719	3,505	-2,916

1-Hour & 4-Hour ramping requirements of electricity system to meet fluctuations due to wind variations based on ten year historic wind profiles for base and high wind scenarios

Appendix E. Definitions

Ancillary Services:

Operating Reserve: In the event of a loss of output from a generation unit or an unexpected change in system demand, it is essential to be in a position to make up the shortfall, either from generation units or other sources. Arranging for customers to reduce their demand requirements can also provide reserve. To cater for different situations that may arise on the transmission system, reserve is contracted over a variety of time scales.

Load Factors: (Taken from Harpur (2009))

Total System Load Factor	TLF
Seasonal Load Factor	SLF
Daily Load Factor	DLF

TLF is defined in the usual way for system load factor. It is the ratio of the mean demand for the year to the peak demand for the year. Working from the full array of half-hourly demands for the year the TLF may be defined as:

$$TLF = \frac{\sum_{w=1,52} \sum_{d=1,7} \sum_{hh=1,48} L_{w,d,hh}}{(52 \times 7 \times 48) \times PeakY}$$

where

$L_{w,d,hh}$ is the load at half-hour hh, day d, week w

and

$PeakY$ is the annual peak

The seasonal load factor, SLF, is defined as the ratio of the average of the daily peaks through the year to the annual peak. So SLF is defined as follows:

$$SLF = \frac{\sum_{w=1,52} \sum_{d=1,7} PeakD_{w,d}}{(52 \times 7) \times PeakY}$$

where

$PeakD_{w,d}$ is the daily peak for day d in week w

In calculating the daily load factor, we must be aware that in fact there is potentially a different load factor for each day of the year. DLF is defined as the average of all these, weighted by the peak of each day. So

$$DLF = \frac{\sum_{w=1,52} \sum_{d=1,7} \left(LFD_{w,d} \times PeakD_{w,d}\right)}{\sum_{w=1,52} \sum_{d=1,7} PeakD_{w,d}}$$

where the daily load factor for day d in week w is given by:

$$LFD_{w,d} = \frac{\sum_{hh=1,48} L_{w,d,hh}}{48 \times PeakD_{w,d}}$$

and

$PeakD_{w,d}$ is the peak for day d in week w

With these formulations it may easily be shown that the total load factor is the product of the seasonal load factor and the daily load factor. That is,

$$TLF = SLF \times DLF$$

Well to Wheel Efficiency: The life cycle assessment, or evaluation of the environmental impact of a product caused or necessitated by its existence.

Appendix F. Outage Data for Adequacy Studies

	Forced Outage (%)	Scheduled Outage (%)
Peat	6	3
Hydro	2.5	1
Pumped Storage	2.5	1.5
Coal	7	3
CCGT	5	2
OCGT & ADGT	3	1
Thermal	6	2
Wind	Wind output was taken from the load. The 1995 profile for wind was selected.	
Interconnector	Assumed the interconnector is fully available.	
Tidal	Assumed available 35% of the time	
Biomass	Assumed available 62% of the time	
Other Small Scale Generation (SSG)	Assumed unavailable 2.5% of the time	

Appendix G. AdCal Description

Taken from Harpur (2009)

AdCal (Adequacy Calculation) is a software package designed to assist in assessing the reliability of electricity power systems. It computes adequacy indices for either a single generation system or for two interconnected systems.

The term adequacy is used here in accordance with the definitions of the North American Reliability Council (NERC). Adequacy is regarded as one aspect of the wider term concept of reliability.

> ***Reliability*** *is the ability to meet the electricity needs of end-use customers, even when unexpected equipment failures or other factors reduce the amount of available electricity.*

NERC breaks down reliability into adequacy and security.

> ***Adequacy*** *is the ability of the electric system to supply the aggregate electrical demand and energy requirements of the end-use customers at all times, taking into account scheduled and reasonably expected unscheduled outages of system elements.*
>
> ***Security*** *is the ability of the bulk electric system to withstand sudden unexpected disturbances such as short circuits or unanticipated loss of system elements due to natural or man-made causes.*

AdCal computes *generation* adequacy indices and therefore is concerned with the ability of the generation units on the system to meet the demand placed on them, taking into account scheduled and unscheduled outages of these units. Transmission or distribution limitations are not considered.

Two main adequacy indices are calculated: LOLE (Loss of Load Expectation) and EUE (Expected Unsupplied Energy). The distribution of LOLP (Loss of Load Probability) across the year may also be obtained. In addition, the program can optionally show a surplus/deficit value in MW terms relative to a specified adequacy target. This target may be expressed in terms of either LOLE or EUE.

The program builds a load model and a generation model, and then analyses for each half-hour in the year the probability that the available generation will fall short of the demand, as well as the extent of any such shortfall. By accumulating these values over the year, the required LOLE and EUE are found. If required, the MW surplus or deficit is found by a built-in iterative process.

Principal Features

Some of the main features of the program are as follows:

- The load model comprises half-hourly MW demands for a 52-week year. Optionally the adequacy analysis may be carried out on a half-hourly, hourly or daily peak basis.
- The analysis may cover an entire year or part of a year by specifying the starting and finishing weeks.
- Up to 25 years may be included in a single study.
- Load data may be read from a spreadsheet, from a binary data file, or built from either source to form a future year load profile with specified energy, peak, and seasonal and daily load factors.
- The generation model requires input data giving the MW capacity, forced outage probability, and scheduled outage duration of each unit. From these data generation probability distributions are constructed which accurately denote the probability of all possible availability states. These distributions are built using a user-specified step size, thus allowing large systems to be modelled without incurring excessive execution time or storage requirements.
- Plant scheduled outages may be provided explicitly, by specifying for each unit the starting and finishing weeks of one or two outage periods each year. Alternatively, if just the total annual duration of the outage for each unit is known, AdCal's maintenance scheduling algorithm may be used to obtain a credible maintenance programme for the year.

- The basic treatment of forced outages comprises a two-state model in which a unit may be available either at full output or not at all. Optionally a multi-state model may be used in which partial availability states are possible. This provides a suitable means for representing combined-cycle plant.
- Pumped storage plant is modelled by a peak-shaving, valley-filling approach. This is designed to maximise the adequacy contribution of the plant. Multiple pumped storage stations may be modelled.
- The capacity of generation units may optionally be changed across the year, for example to model ambient temperature effects, by specifying appropriate weekly factors.
- The principal output consists of the Loss of Load Expectation (LOLE) and Expected Unsupplied Energy (EUE) for each case analysed. The LOLE is the expected number of hours for which the available generation capacity will be less than the demand. The EUE is the expected energy shortfall resulting from such deficiencies.
- As well as the total LOLE and EUE for the year (or part of the year if appropriate), more detailed results are also possible:
    - weekly LOLEs and EUEs
    - half-hourly loss of load probability (LOLP) values for the year.
- Optionally the user may specify a target adequacy standard, either in terms of LOLE or EUE. In this case, the program computes the surplus or deficit in MW terms relative to the standard. Using the simplest form of this feature gives the amount of perfect plant (that is, plant with 100% availability) that needs to be added or subtracted in order to attain the standard.
- The adequacy implications of two interconnected systems may also be examined. In this case all the required load and generation data needs to be provided for each system as well as the capacity and availability of the interconnection between them. The resulting LOLE and EUE indices for each system are found, assuming that each side assists the other to the extent of any surplus capacity it has at any

time. A different type of interconnection agreement may also be modelled, in which any overall deficit is shared between the two parties in proportion to their demands.