www.store-project.eu

Facilitating energy storage to allow high penetration of intermittent renewable energy

Power system overview and RES integration

Ireland

Source: (ESB)

Supported by INTELLIGENT ENERGY EUROPE

Acknowledgements

This report has been produced as part of the project "Facilitating energy storage to allow high penetration of intermittent renewable energy", stoRE. The logos of the partners cooperating in this project are shown below and more information about them and the project is available on www.store-project.eu

The work for this report has been coordinated by UCC and HSU.

Author(s) and Contributors		
Name	Organisation	Email
Thomas Weiss (Author)	HSU	thomas.weiss@hsu-hh.de
Annicka Wänn (Author)	UCC	annicka.wann@gmail.com
Paul Leahy	UCC	paul.leahy@ucc.ie
Edward Mc Garrigle	UCC	e.mcgarrigle@umail.ucc.ie

Table of Contents

Supported by INTELLIGENT ENERGY EUROPE

Executive Summary

Key Points

1. Under current development plans, wind generation will sometimes exceed total demand for power on the Irish system by 2020, particularly in wintertime when the winds are strongest.

2. This excess wind power can either be exported via interconnectors to GB, rejected (curtailed), or stored.

3. Due to the fact that wind power output in Ireland and GB is highly correlated, it cannot be guaranteed that the GB system will always be able to accept imports of surplus wind from Ireland.

4. For the same reason, adding further interconnection capacity, beyond that planned for 2020, will only allow a small increase in wind power exports.

5. Additional energy storage capacity would be able absorb wind energy that would otherwise have to be rejected.

6. To fully integrate all the wind energy output under a 40% RES-E scenario in 2020, a very large energy storage capacity would be required: up to 70GWh at 1.8 GW power rating. These requirements increase even further if a higher, 80% RES-E scenario is considered. In reality, storage capacity will be limited by costs and market conditions, factors which are addressed by the other workpackages in stoRE.

7. This study shows clear benefits for additional energy storage capacity by 2020, including increased overall RES-E share and a reduction in curtailment of wind energy.

1. Introduction

The information and discussions presented in this report are part of the European project stoRE (www.store-project.eu). stoRE aims to facilitate the realization of the ambitious objectives for high penetration of variable renewable energies in the European grid by 2020 and beyond, by unlocking the potential for implementing energy storage. In the stoRE project the focus of analysis and discussions is predominantly on bulk energy storage technologies (EST), namely pumped hydro energy storage (PHES) and compressed air energy storage (CAES).

Work-package 5 (WP5) of the stoRE project aims to identify regulatory and market barriers to the development and operation of electricity storage systems (ESS) in the six target countries (Austria, Denmark, Germany, Greece, Ireland and Spain). This document, Deliverable 5.1 (D5.1), addresses this by providing information on the electricity storage needs of each target country to integrate future RES-E generation into their electricity systems.

This study focuses on the power system of the Republic of Ireland (ROI) and its potential for renewable energy integration. The aim of the report is to discern the need for energy storage in different scenarios while taking into account interconnector capacity to Great Britain (GB). The island of Ireland consists of two jurisdictions, the ROI and Northern Ireland (NI). From a grid perspective however, the island of Ireland operates as one synchronous system and, since 2007, under a single electricity market. For this purpose, wherever deemed necessary from an island of Ireland perspective, information on NI has been taken into account.

The electricity grid in the ROI is a centralised system due to the presence of several large base load thermal plants. However, it has a certain level of flexibility due to several peaking plants

Supported by INTELLIGENT ENERGY EUROPE

(gas turbines) and also one pumped hydro energy storage (PHES) facility. This report firstly contains a survey and review of the existing electricity system and proposed future developments. This information is then used to derive a reference scenario and various future development scenarios. The scenarios assume varying levels of future RES-E capacity, energy storage capacity and interconnection capacity. The results of computer simulations of the scenarios are presented, and these results are used to determine the energy storage needs for each scenario.

2. System data and future scenarios

Power plant mix and energy production

The island of Ireland is heavily dependent on imported fossil fuels and in 2012 roughly 70 % of the installed capacity is thermal plants; the installed capacity from renewable energy sources (RES) in the ROI and NI is roughly 22 % and 15 % respectively and the total electricity requirement in the ROI and NI was 26.3 TWh and 9.0 TWh, respectively.

In recent years two new large combined-cycle gas turbines (CCGT) have been commissioned in the ROI. A further CCGT is expected to replace a unit that is to be decommissioned within the next decade. Furthermore, four new open cycle gas turbines (OCGT) and a Waste-to-Energy facility are also expected to be built during the next decade. In NI no further conventional generation is currently planned for the next decade.

Transmission system and planned reinforcements

There are two transmission system operators (TSOs) on the island, EirGrid in the ROI and SONI Ltd in NI. Lines in the ROI are 110 kV, 220 kV and 400 kV rated whereas in NI there are 110 kV and 275 kV lines.

Extensive transmission system upgrades are planned within “Grid 25”, which is EirGrid’s Grid Development Strategy to develop and upgrade the transmission network in the ROI by 2025. “Network 25” is NI’s equivalent of Grid 25.

Interconnections

Until recently, there was only one interconnector from the island of Ireland to the GB system, the Moyle Interconnector. It links Northern Ireland to Scotland with a capacity of 500 MW. In December 2012 operation of the new East-West interconnector commenced; it connects the ROI and GB directly with a capacity of 500 MW. Further planned interconnectors include an additional, internal North-South interconnector which will strengthen the grid system between NI and ROI. The ISLES Project also examined options for connecting future off-shore and near-shore development to the mainland in the ROI and Scotland.

National Energy Plans for the Future

The Irish Renewable Energy Action Plan (NREAP) forms the basis for renewable energy policy in Ireland. The ROI and NI have both committed to a target of 40 % of final consumption of electricity from renewable sources by 2020, the main bulk of which is expected to be generated by wind power. Wind power is currently the most abundant renewable energy source on the island of Ireland due to the onshore wind resources representing some of the most effective renewable resources in Europe and offshore benefiting from Ireland’s extensive area of offshore territory in the Atlantic and the Irish Sea. As a consequence, it is expected that the RES share of installed generation capacity will more than double in the ROI and will more than treble in NI by 2020. The energy mix will thus look very different in 2020 compared to 2010 (see Figure 1).

Thoughts are also being given to the energy system beyond 2020 in the shape of Roadmaps

Supported by INTELLIGENT ENERGY EUROPE

published by the Sustainable Energy Authority Ireland (SEAI). There are six individual roadmaps with some overlap: Smart Grid, Wind Energy, Bioenergy, Marine Energy, Residential and Electric Vehicles.

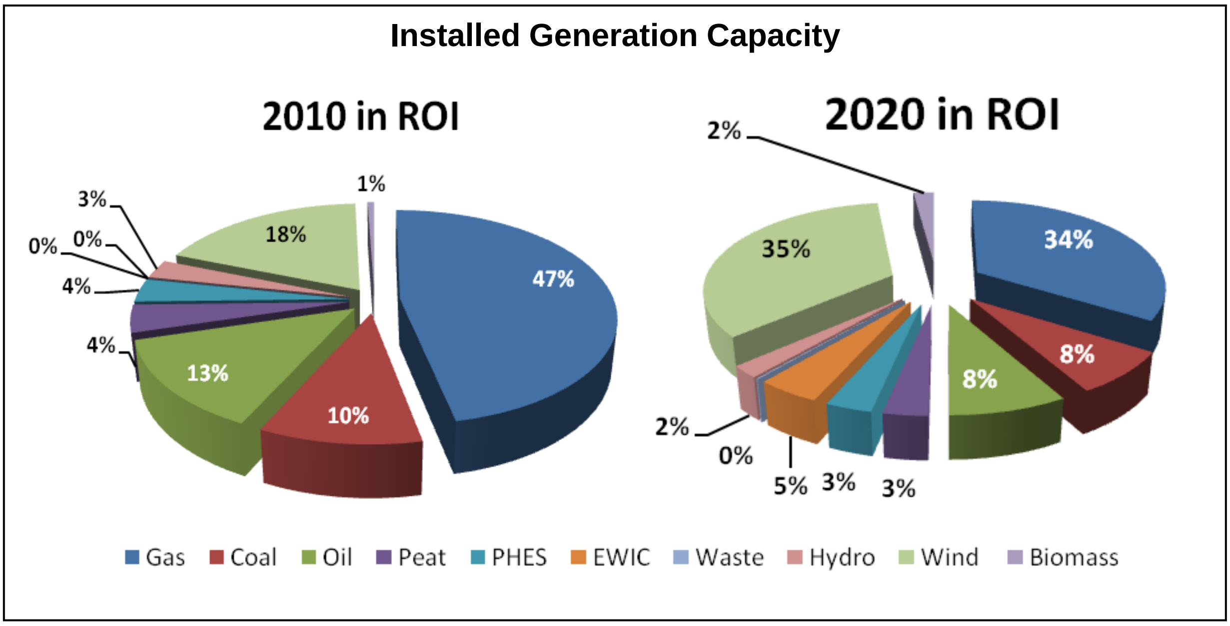


Figure 1: Current (2010) and forecasted (2020) installed generation capacity for ROI. Source: (EirGrid and SONI, 2010, EirGrid and SONI, 2011, EirGrid and SONI, 2012b)

Energy Storage Development Plans

In the ROI there is currently only one bulk energy storage facility, the PHES facility Turlough Hill. Commissioned in 1974, it has an installed capacity of 292 MW. In NI there is no bulk energy storage facility.

Already in 2011, EirGrid and Soni (2012a) reported wind curtailment levels of 2.2 %. Several studies have been made in regards to the expected level of curtailment in 2020; these show figures of between 4 -15 % (EirGrid and SONI, 2012b, Mc Garrigle et al., 2013, O'Sullivan, 2012). Furthermore a study carried out by Eirgrid (2009) has shown a cost analysis of the potential benefit of PHES. However, the study focuses more on the economic benefit of PHES rather than the technical benefits of PHES to the grid.

In 2011 Turlough hill was unavailable due to extensive maintenance works and it is notable that during this time higher levels of curtailment were reported than would otherwise have been expected.

Although the NREAP and the latest DCENR report on Strategy for Renewable Energy: 2012-2020 (2012) recognize that large scale storage facilities, specifically PHES and CAES, merit attention, no overall plan exists yet for these infrastructures.

Nevertheless, there has been an increased interest in PHES developments. Currently, only one connection agreement has been signed for a PHES facility, which would have an installed capacity of 70MW. However, there is also a proposal for a sea water PHES on the west coast of the ROI, which would store excess wind energy from the surrounding wind parks. The electricity would be transported to and fed into the East-West Interconnector for GB energy consumption.

Supported by INTELLIGENT ENERGY EUROPE

3. Reference and Future Development Scenarios

A reference scenario and two scenarios for future RES development are explored in order to assess the future need for bulk energy storage in the ROI's electricity system. The reference scenario is based on the year 2011. The first future scenario concerns the year 2020, when, according to the Irish NREAP the RE share in electricity production will reach 40%. Three different penetration levels of onshore and offshore wind are investigated. The second scenario examines the impact on the electricity system with a greater demand and an RE share of 80%; it is not associated with any particular year. Furthermore, this scenario also studies the influence of additional interconnection capacity to GB. Table 1 provides an overview of the scenarios.

Table 1: Renewable energy capacities and load characteristics of the scenarios investigated

Scenario:	Ref.	2020 Scenario (in MW)			80% RES Scenario (in MW)	
Case:		A	B	C	A	B
Wind (onshore)	1655	4094	4000	4200	9200	Import/export investigations
Wind (offshore)	25	555	100	600	3900	
Photovoltaic (PV)	0	0	0	0	0	0
Hydropower	237.7	238			238	
Other RES	1.1	1.1			1.5	
Yearly peak load (GW?)	4.64	5.87			7.87	
Annual demand (TWh)	25.8	32.71			45	
RE production (TWh)	4.25	13.08	11	14	36	
RE share	16.5%	40%	33.6%	42.8%	~80%	

Residual Load and Rejected Energy

The residual load (RL) is defined as the load demand minus wind power production minus the non-controllable portion of hydropower. A negative RL indicates that there is a surplus of fluctuating renewable energy that needs to be either stored, exported or curtailed and a positive RL indicates load that needs to be covered by either conventional or controllable renewable power plants, imports or recovered from energy storage.

The rejected energy is the energy from fluctuating renewable sources that cannot be integrated onto the grid. In other words, it is the energy that is initially rejected if there is no energy storage system or transmission lines (or interconnectors) to neighbouring countries. The load and RL for GB was also modelled in order to estimate flows on the interconnector between the two regions.

a. Cases examined within the 2020 Scenario

Three different cases were investigated for the year 2020 scenario: Case A (40 % RES), Case B (33 % RES) and Case C (42 % RES). As already mentioned, the main contribution is expected to come from wind power, therefore each case varies in the total amount of wind energy and also in the relative proportions of onshore and offshore wind power.

Already in 2020 the RL in ROI is negative for some of the time (see Figure 2), which indicates a surplus of fluctuating renewable electricity that can be exported, stored or else needs to be curtailed. Also shown in Figure 2 is the RL for Great Britain. GB and ROI RLs look similar over the full year but the GB load is approximately 10 times larger than that of the ROI.

Supported by INTELLIGENT ENERGY EUROPE

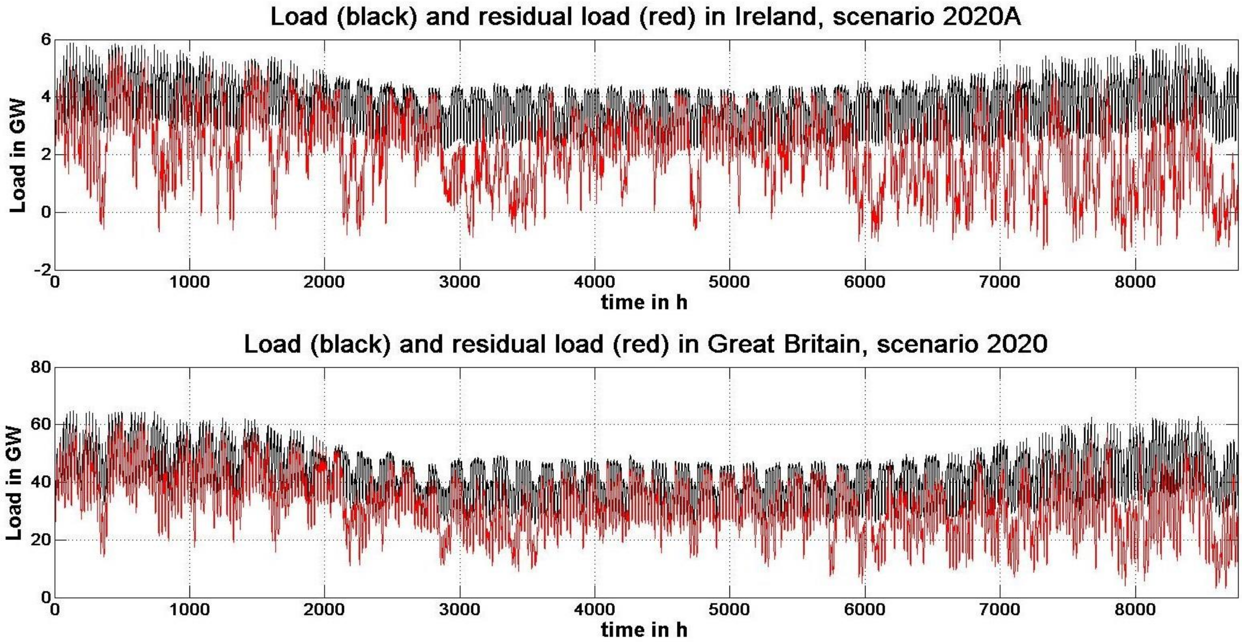


Figure 2: Load demand (black) and residual load (red) in Ireland (above) and Great Britain (below)

As expected Case C, with the highest shares of RES also had the highest amount of rejected energy, Case B with the lowest shares of RES had the lowest amount of rejected energy and Case A with the medium level of RES share also had a medium level of rejected energy. In Case A for example the rejected energy reaches 0.5 TWh.

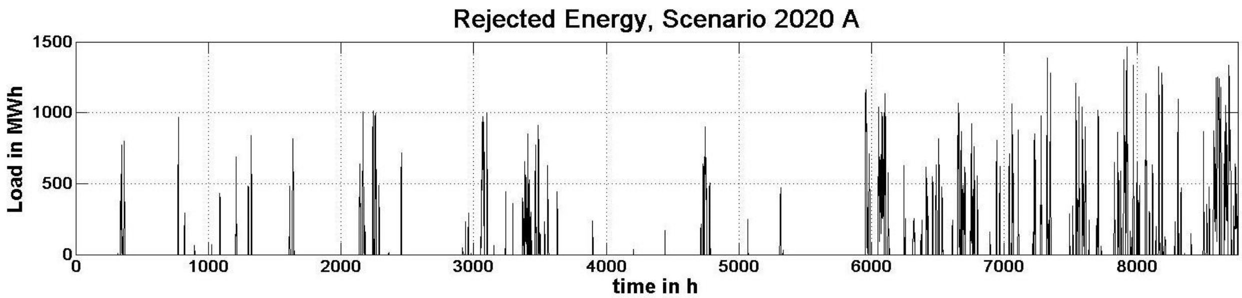


Figure 3: Rejected energy in Scenario Case A at hourly value for the full year

b. Cases examined within the 80 % Renewable Energy Scenario

Two cases were investigated within this scenario. The first, case A, studies the ROI with an 80 % share of renewable energy and no interconnector capacity and case B studied the same system but with interconnector capacity. For this reason, a simplified British system was also modeled. As can be seen in Figure 4 for the ROI, the spread between maximum and minimum power of the residual load increases significantly compared to the 2020 scenario, and especially in regards to load demand.

Supported by INTELLIGENT ENERGY EUROPE

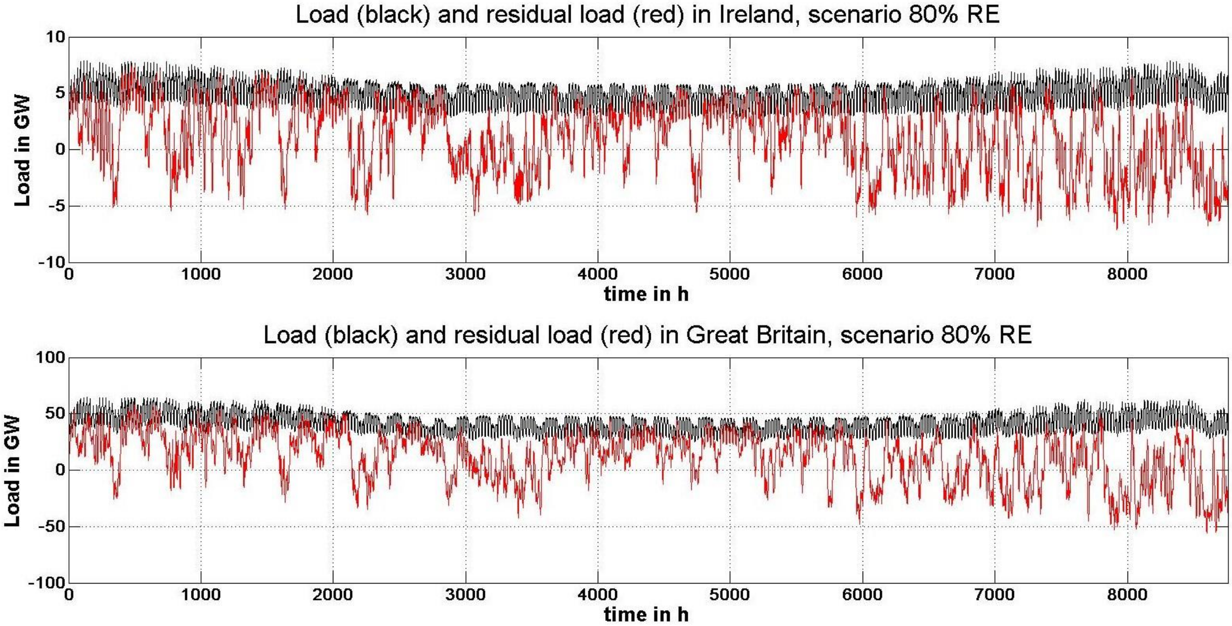


Figure 4: Load demand (black) and residual load (red) in Ireland (above) and Great Britain (below)

The rejected energy levels for the 80 % RE scenario reaches 7.7 TWh. This amount of energy is already 22 % of the total predicted feed-in from renewables in this scenario.

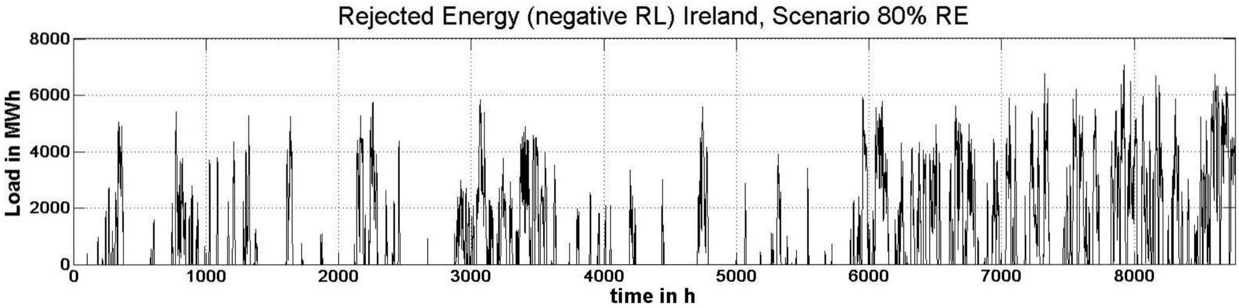


Figure 5: Rejected energy in Scenario 80 % RE at hourly value for the full year

Load Variations

The load variation was also simulated for the 2020 Scenarios in GW per 1 hour, 3 hours and 8 hours, to estimate the flexibility needed in the electricity system. The results show that with increasing feed-in from wind power the variations in the residual load also increase; the maximum of these variations is especially increasing in comparison to the load demand. This indicates that the electricity system will have to become more flexible to be able to adapt more quickly to high load variations in a positive as well as negative direction.

4. Energy Storage Needs for Future Development Scenarios

To determine the energy storage needs, an algorithm has been developed at the Helmut-Schmidt-University to estimate the energy storage needs from a system point of view. The aim of the energy storage facilities in this approach is to integrate the maximum renewable energies possible without any focus on the electricity spot market price.

To calculate the overall energy storage needs, two energy storage systems are integrated in the simulation. The first system consists of the already existing energy storage facilities plus any expected expansion of these. The second system has an unlimited capacity and power and is not linked to any specific storage technology. The second system is useful because the actual power and storage capacity used in this case is an indicator of what would be required of a notional future energy storage system if the goal is to maximise integration of RES-E. The simulations are summarised in Table 2.

Table 2 Summary of energy storage capacities simulated under different scenarios

Scenario	2020 Scenario	80% RES Scenario
Unlimited energy storage capacity	A, B, C	A, B
Existing (2011) energy storage capacity	A, B, C	A, B

Residual Load and Load Variation with Energy Storage

a. 2020 Scenario

The unlimited storage capacity of system 2 means that zero wind energy is rejected. The need for energy storage capacity as determined by system 2 is fairly similar between Case A (59 GWh) and Case C (70 GWh), in that the RES shares are also high in these two cases. As expected Case B, which has the lowest RES share, also has the smallest need for additional storage capacity. The need is significantly smaller than in Case A and C at 14 GWh.

Adding energy storage to the system has decreased the large load fluctuations in all three cases. This enables the other generation units to react more easily to the load variations; furthermore the use of energy storage allows for better management of slow-responding thermal power plants.

b. 80% Renewable Energy Scenario

In this scenario one of the notable differences as compared to the 2020 scenario is that the residual load is negative for long periods of time. This means that the storage units are also used less than in the 2020 scenario, because they reach their limit more frequently and have to wait for the residual load to turn positive again so that they can discharge.

The simulation data is based on a particular wind year. 2011, has very high feed-in from wind in the latter half of the year. This results in an continuously growing need for energy storage capacity. To fully integrate all of the wind power therefore, a storage capacity of 2.77 TWh would be needed.

Correlation between Wind Power in Ireland and the UK

To better understand the interaction of energy storage in ROI and interconnections to the UK, the correlation between wind power production in the ROI and GB had to be investigated. The normalized wind energy production for both countries is shown in Figure 6 for the final ~1/3 of the year, hours 6000 to 8760. The two curves are very similar, and lagged cross-correlation calculations show that there is an average lag time of four hours between Ireland and GB. In other words, wind peaks experienced over Ireland will be experienced over the UK 4 hours later, on average.

Supported by INTELLIGENT ENERGY EUROPE

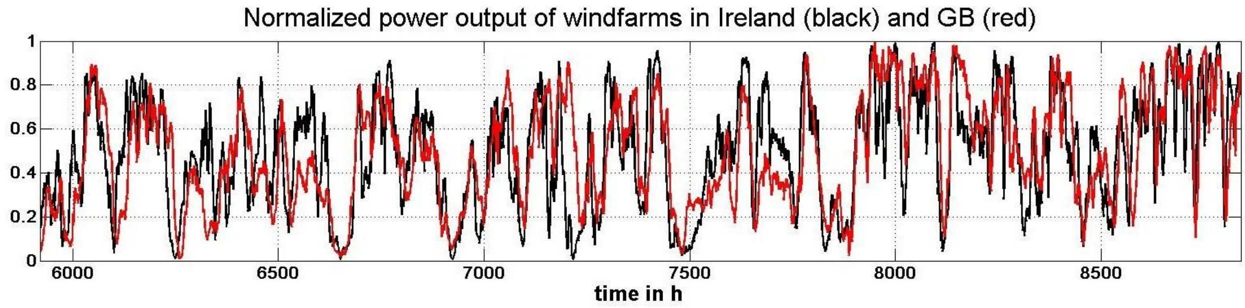
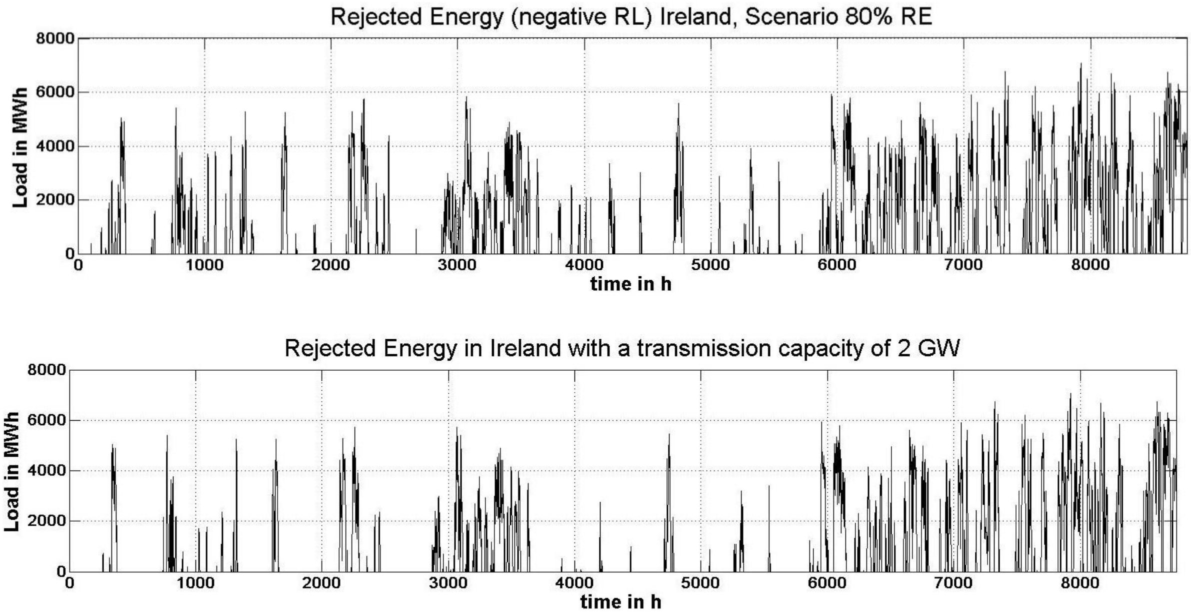


Figure 6: Normalized wind power production in Ireland (black) and Great Britain (red) for hours 6000 to 8760.

Transmittable Energy with different interconnection capacities

An interconnector capacity of 2 GW was introduced into the next scenario. It is interesting to compare the case of rejected energy in the ROI with zero interconnector capacity to GB with the case *with* a 2 GW interconnector capacity (see Figure 7). Remarkably there is only a slight difference between the two cases. Furthermore, simulations show that the interconnectors are not in use for a large proportion of the time, particularly after hour 7500 to year end. This is due to two reasons: first, during times of no surplus there is no need to export energy from a grid perspective; and second, during times of surplus energy in the Irish grid it is likely that there is a surplus in the British grid as (due to the high correlation factor) and the otherwise transmitted energy cannot be used in the British system.

A situation of an unlimited interconnector capacity was also investigated. Remarkably, this did not considerably change the amount of rejected energy or the transmitted energy, which suggests that an widespread expansion of interconnection capacity would be of little benefit to the Irish system.



(a)

(b)

Figure 7: Rejected energy for Ireland (a) without and (b) with an interconnector capacity of 2 GW.

Conclusions

Energy Storage needs without Interconnection

The results from the 2020 scenario show that with current development plans (excluding interconnections) the residual load will turn negative some of the time, especially in the autumn and winter months when there are sustained and strong surpluses of wind. Any excess wind generation during these periods is likely to be curtailed. PHES or CAES can help address this problem by increasing the effective system load, and have the added benefit of contributing to system stability as synchronous generation sources. Additional energy storage can help abate the otherwise rejected (curtailed) energy. Other possible technical solutions to this problem include the construction of hybrid wind/PHES plants, or wind turbines that can emulate synchronous generators for short periods of time. Similarily, the load variation becomes more manageable implying that there is a need for further flexibility in the operation of the electricity grid.
The results from the 80% RE share scenario showed the same tendencies as in the 2020 scenario only in that the grid issues become amplified. The need for storage capacity reaches 2.7 TWh.

It should be noted that the calculated results show the total need for energy storage capacity should no wind curtailment take place. This is only of theoretical value. The available sites for PHES development in Ireland are limited, especially in terms of GWh storage capacity, and it would not be practically or economically possible to construct this type of scenario using PHES alone. Nevertheless, it is useful to study as it represents the upper bounds of what is possible with energy storage technology in general.

Influence of Interconnections

There is a high correlation between wind generation in ROI and wind generation in GB at an hourly level. The peak correlation occurs with a four-hour time lag, i.e. peak wind generation in GB appears typically four hours later than in Ireland. The influence of the correlation factor becomes apparent in the results for the need for interconnections.
Two different interconnection capacities were investigated, 2GW and unlimited capacity. The results show very little difference in rejected energy, 6.1 TWh and 5.7 TWh respectively. The high level of correlation between Ireland's wind generation and GB wind generation means that prolonged periods of high exports of surplus wind are unlikely to occur. The pattern of interconnector usage is more likely to be dominated by shorter term fluctuations.

Energy storage needs and Interconnections

The results of simulating the need for energy storage capacity needs in a system that either has 2 GW or unlimited interconnection capacity are very similar to the energy storage needs in a system without interconnection capacity. In both cases a notional energy storage capacity need of approximately 2.7 TWh is needed in order to reduce rejected RES-E to zero. This implies that an extensive extension of interconnection capacity would not bring much benefit for the Irish system, from the point of view of increasing RES integration and reducing curtailment[1].

[1] Additional alternating current (AC) interconnectors to GB could still bring the benefit of integration into a larger system with a higher proportion of synchronous generation, allowing greater penetration of ROI-based non-synchronous wind generators without a risk to overall system stability. Given that the dominant interconnection technology is currently HVDC this is considered unlikely to happen in the near future.

Supported by INTELLIGENT ENERGY EUROPE

1. Introduction

The information and discussions presented in this report are part of the European project stoRE (www.store-project.eu). stoRE aims to facilitate the realization of the ambitious objectives for high penetration of variable renewable energies in the European grid by 2020 and beyond, by unlocking the potential for implementing energy storage. In the stoRE project the focus of analysis and discussions is predominantly on bulk energy storage technologies (EST), namely pumped hydro energy storage (PHES) and compressed air energy storage (CAES)[2].

Bulk EST are expected to be one of the key enabling technologies for the integration of large amounts of variable electricity generation from renewable energy sources (RES-E). In particular, the ability to quickly discharge large amounts of stored electricity or to reduce loads during certain points in time throughout a day (i.e. output smoothing)[3] can mitigate many challenges that arise from high shares of variable RES-E generation in the electricity system. Furthermore, bulk EST could also play an important role in optimising the physical and financial functioning of electricity markets and the corresponding commercial energy trading activities[4]. Work-package 5 (WP5) of the stoRE project aims to identify regulatory and market barriers to the development and operation of electricity storage systems (ESS) in the six target countries (Austria, Denmark, Germany, Greece, Ireland and Spain). For achieving that, this document, Deliverable 5.1 (D5.1), provides information about the electricity storage needs in each of the target countries necessary for integrating future RES-E generation into their electricity systems.

This report focuses on the Republic of Ireland (ROI), with an aim to determine the need for bulk energy storage capacity in the Republic of Ireland (ROI) by investigating future development plans for the year 2020 and also an 80 % renewable energy share penetration. Furthermore, this report considers the impact of interconnector capacity to Great Britain (GB).

Although this report will focus on the ROI, it is important to note that the island of Ireland consists two jurisdictions, the ROI and Northern Ireland (NI). From a political view the ROI is an independent country, whereas NI is one of four regions that form the United Kingdom (UK). From a grid perspective however, the island of Ireland has a single grid and a single electricity market.

As interconnections to GB and Europe are presently weak, the island of Ireland can be described as an “isolated grid”. Furthermore, due to a large stock of thermal generating units the Irish grid is also “centralised”. There is however, a certain level of flexibility in the system due to several peaking plants (gas turbines) and also the energy storage unit.

This report is separated into three main sections. Chapter 2 explores the current system data and future scenarios available in mainly the ROI but also in NI. In Chapter 3 the future development scenarios are introduced and the results regarding residual load and rejected energy in an isolated grid are presented. Finally in Chapter 4, the results of energy storage capacity in an isolated grid and with interconnector capacity are presented.

Please note that the distinction is made between ROI and NI and when referring to both ROI and NI the term “island of Ireland” or “All-island” will be used in this report. Furthermore, this

[2] For a complete picture of energy storage options see Deliverable 2.1 (Zach et al., 2012b) of the stoRE project, which also provides a brief overview of other (non-bulk) EST being outside the scope of stoRE.

[3] Other benefits of bulk EST, i.e. black start capability, area control, frequency response (secondary and tertiary control) etc., are described in Deliverable 2.1 in detail.

[4] See Deliverable 2.2 (Zach et al., 2012c) of the stoRE project for more details about the role of bulk EST in future electricity systems with high shares of RES-E generation.

Supported by INTELLIGENT ENERGY EUROPE

report only investigates the need for energy storage from a grid perspective. No market analysis has been conducted.

Supported by INTELLIGENT ENERGY EUROPE

2. System Data and Future Scenarios

This chapter presents an overview of the current electricity system with regards to power plant mix and energy production on the island of Ireland, the transmission system and planned reinforcements, current and future plans for interconnections, national energy plans for 2020 and 2050, and current and further energy storage development plans.

2.1. Power Plant Mix and Energy Production

The total electricity requirement (TER) in ROI and NI was 26.3 TWh and 9.0 TWh respectively in 2012. TER peak the same year was 4.7 GW and 1.7 GW respectively for ROI and NI (EirGrid and SONI, 2012b).

Currently ROI has 19 thermal installations, of which, 8 use natural gas (3739 MW), 4 use oil (1130 MW), 3 use peat (346 MW), 1 uses coal (847 MW) and 1 uses waste (15 MW) as its main source of fuel. There are a further 4 large hydropower schemes of which the largest has a capacity of 86 MW and 1 Pumped Hydro Energy Storage facility with an installed capacity of 292 MW. Since 2012 there is also an interconnector between the ROI and Wales with an installed capacity of 500 MW. In NI there are 9 thermal installations, of which, 4 use natural gas (1508 MW), 4 use oil (337 MW), and 1 uses coal (476) as its main source of fuel. There is also an interconnector from NI connecting to Scotland with an installed capacity of 450 MW.

Table 2 shows the installed capacity (MW) and electricity generation (GWh) in ROI and NI in 2011 separated by source. Forecasted for Certain discrepancies in data were found between different reports.

Table 2: Installed capacity (MW) and electricity generation (GWh) on the island of Ireland by source in 2012. Source: (EirGrid and SONI, 2012b, ENTSO-E, 2012)

	Thermal	PHES	Hydro	Wind	Bioenergy	Other RES	Total
Installed Capacity (MW)							
ROI	6062	292	237	1642	59	15	8747[1]
NI	2321	-	4	467	23	3	3268[2]
Electricity Generation (GWh)							
ROI	20419	194[3]	761	4030	n/a	n/a	25653

[1]Including the East West Interconnector of 440MW
[2]Includes the Moyle Interconnector of 450MW
[3]Turlough hill was unavailable in 2011 and only came back online in the second quarter of 2012

In recent years two large combined-cycle gas turbines (CCGT) have been commissioned in the ROI providing an additional 690MW to the electricity system. It is furthermore expected that within the next 10 years a new CCGT plant with an additional 215MW will replace the unit to be decommissioned at Great island; A Waste-to-Energy plant will be built to supply 62MW; and four new open cycle gas turbines (OCGT) units supplying an additional 349MW will be built. One further CCGT unit of 440MW is in the pipeline but has yet to receive a commissioning date (EirGrid and SONI, 2012b). In NI no new conventional generation is currently planned over the next ten years. Figure 8 shows the distribution of dispatchable plants on the island of Ireland. The installed capacities are the forecasted capacities for 2018.

Supported by INTELLIGENT ENERGY EUROPE

Wind power is currently the island of Ireland's main renewable energy source (RES). In the ROI and NI there is currently 1642 MW and 467 MW installed respectively (EirGrid and SONI, 2012b). Figure 9 shows the location of the existing and planned wind farms as of October 2011. Planned refers to those wind farms that have signed a connection agreement with EirGrid in ROI and those that have received planning approval in NI (EirGrid and SONI, 2011).

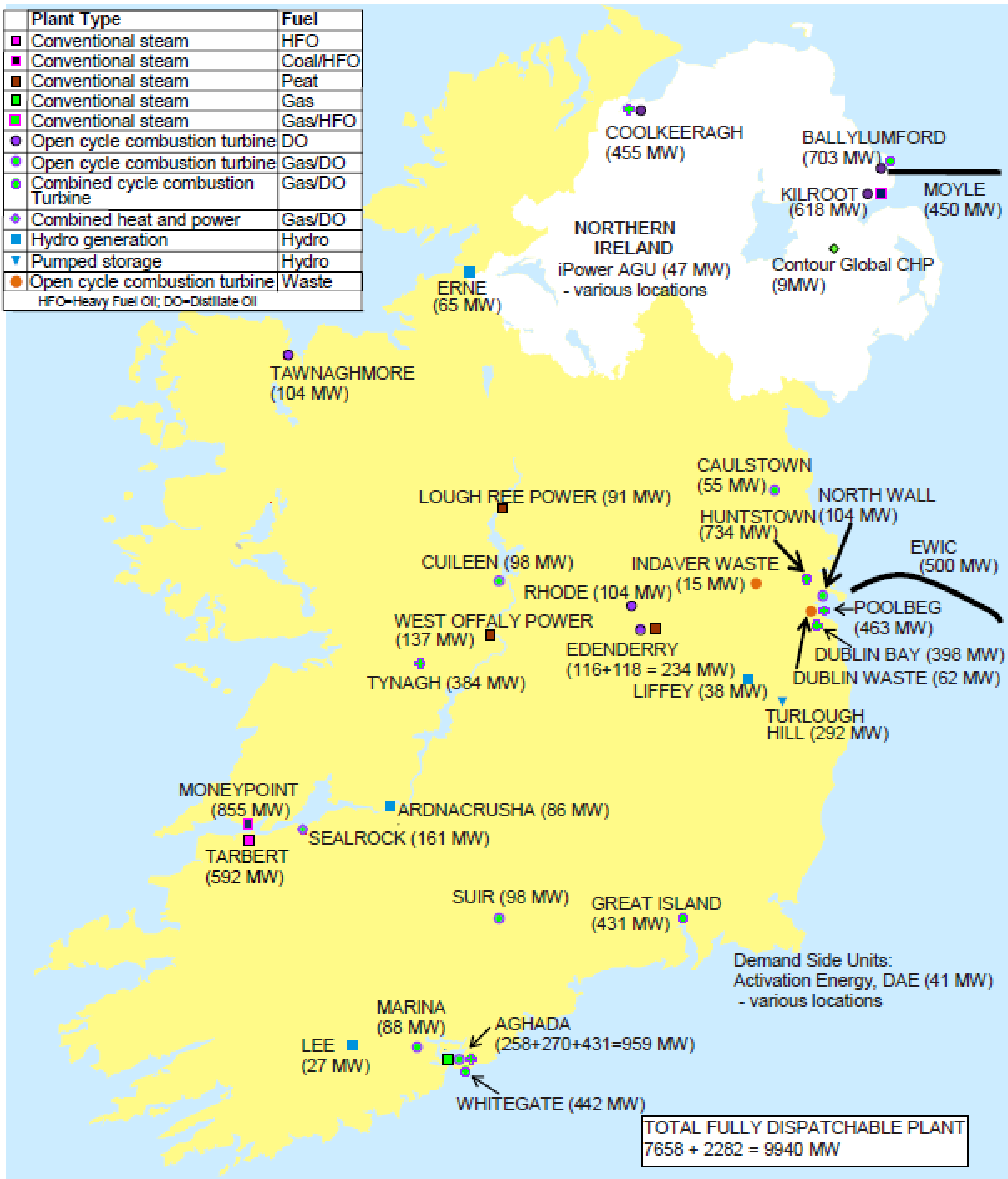


Figure 8: Fully dispatchable plant and interconnectors installed in 2018, at exported capacities. Source:(EirGrid and SONI, 2012b)

Figure 9: Existing and planned wind farms as of October 2011. Source: (EirGrid and SONI, 2011)

Supported by INTELLIGENT ENERGY EUROPE

2.2. Transmission system and planned reinforcement

The island of Ireland has two Transmission System Operators (TSO) and one Market Operator (MO); Eirgrid plc is the licensed TSO in the ROI but is also the owner of the System Operator Northern Ireland (SONI Ltd) the TSO in NI (Eirgrid, 2012a). Since 2005 the two jurisdictions operate under a single wholesale electricity market (SEM) and with dual currencies that is managed in cooperation between Eirgrid plc and SONI Ltd by a joint venture known as SEMO (the Single Electricity Market Operator). The SEM includes approximately 1.8 million and 0.7 million electricity consumers in ROI and NI respectively (semo, 2012).

The responsibility of the TSO is to develop the transmission network which in ROI consists of 110/220/400kV lines, substations and cables. The distribution system operator (DSO) in the ROI is the ESB networks that are responsible for developing the distribution network which comprises distribution 110kV lines (tail lines not part of the meshed transmission grid) and lower voltage lines. (DCENR, 2010)

The transmission network on the island of Ireland comprises of 110 kV and 220 kV cables and lines, 220 kV, 275 kV and 400 kV lines. The main lines within the ROI are 110 kV and 220 kV, whereas in Northern Ireland the main lines are 110 kV and 275 kV (see Figure 10).

In addition, two 400 kV lines run across the ROI from West to East bringing electricity from the thermal power plant, Moneypoint to Dublin and the surrounding area. As the main source of electricity on the island of Ireland is thermal power, the transmission network is characterised as “centralised” with the main transmission lines connecting the large electricity production plant to areas where end users are concentrated. This has been a main concern for wind farms but also for other renewable generators. The reason is that wind farms are being built in areas that are not well connected in terms of the transmission network.

2.2.1. Gate Connections

The Commission for Energy Regulation (CER) regulates both the transmission and distribution network discussed earlier. It is also responsible for setting the policies related to generators (including wind farms) seeking to connect to the network (CER, 2010). Furthermore, the CER has a wider role in setting allowed network costs and tariffs, which feed through into the end-cost of electricity.

A “Gate” system was launched at the end of 2004 to process wind farm applications by geographic location. Previously applications had been processed one by one making this process inefficient in the late 1990s and early 2000 due to the large number of wind farm applications that were received. So far there have been three “Gates” known as Gate 1, Gate 2 and Gate 3 bringing the total of planned new connections since the launch of Gate 1 to 5665 MW.

To date (October 2012) onshore wind farm installments total 1701 MW in the ROI and 443 MW in NI (IWEA, 2012b). Off-shore, so far, there is the Arklow bank project (phase 1) which is a 25 MW partnership between Airtricity and GE Energy (IWEA, 2012a). If all the new Gate 3 renewable energy projects are built (and subsequently connected) within this decade Ireland will have more than 6,000 MW installed capacity of wind power (CER, 2010).

To allow for new wind farm connections the development plan, Grid 25 is essential (see further information below). Renewable generators will be granted full access to the grid in line with the available capacity already on the grid and the Grid 25 upgrades planned for the areas in which they are connecting (CER, 2010).

Supported by INTELLIGENT ENERGY EUROPE

The CER has not yet made a decision on the next "Gate" or how generator applications will be processed after Gate 3 (CER, 2010).

2.2.2. Grid 25

Grid 25 is Eirgrid's Grid Development Strategy to develop and upgrade the transmission network in the ROI until 2025. The plans include constructing 1,150 km of new power lines and upgrading 2,300 km of existing lines which will in effect double the size of the electricity grid to date. The plans also include strengthening the grid between the ROI and NI by increasing integration of the network between County Donegal and NI as well as through the North-South interconnector. The network extensions also include interconnectors to the UK. According to the plan, "It will not be possible to utilise Ireland's natural resources of renewable energy without the essential upgrades outlined in GRID**25**" (Eirgrid, 2008).

2.2.3. Network 25

Network 25 is NI's equivalent of Grid 25. It aims at developing roughly 400 km of 275kV lines and 450 km of 110kV lines(Brown, 2009). Grid 25 and Network 25 are working together closely.

2.2.4. The DS3 Programme

The DS3 programme (EirGrid et al., 2012) was launched in 2011. It aims to deliver a secure, sustainable electricity system by developing solutions to the challenges associated with increasing levels of renewable generation, particularly with regards to secure power system operations.

The island of Ireland's power system is already operating with one of the highest percentage of RES anywhere in the world relative to the size of the system. To tackle this unique challenge the DS3 programme brings together several aspects, including development of financial incentives for better plant performance, and development of operational policies and system tools to use the portfolio to the best of its capabilities. Another aspect of the DS3 programme is the System Service Review which evaluates products, other than energy, that are required for the continuous, secure operation of the power system. The objective of the programme is that together with Grid 25 and Network 25 and all other parties, the island of Ireland reaches its' 40% renewable electricity target in a cost efficient manner without adversely affecting security of supply of the all-island power system.

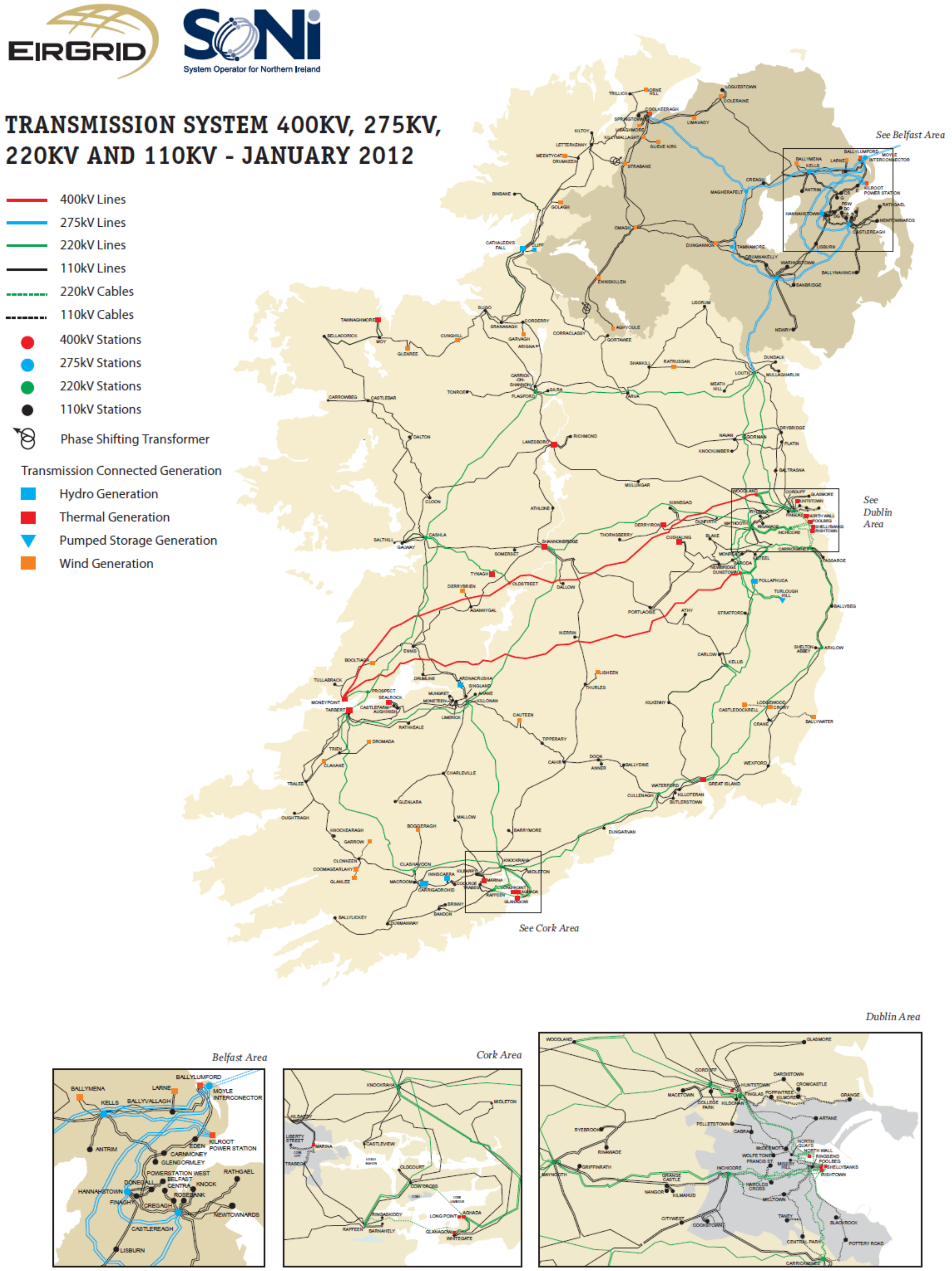


Figure 10: All – island Transmission system with enlargements of Belfast, Cork and Dublin area. Source: (EirGrid and SONI, 2012c)

Supported by INTELLIGENT ENERGY EUROPE

2.3. Interconnections

As already discussed in Chapter 2.2. the network connections between ROI and NI are in the process of being upgraded as part of Grid 25. Until recently, there was only one interconnector from the island of Ireland, the Moyle Interconnector. It links Northern Ireland to Scotland with a capacity of 500 MW and is available for third party access (mutual*energy*, 2009).

As part of Grid 25 the East-West Interconnector has been established to connect the Irish power system to the British electricity grid between Rush in Co. Dublin and Barkby Beach in North Wales. It allows for a further two-way flow of electricity with a capacity of 500MW. Operation of the interconnector commenced in December 2012. (Eirgrid, 2012b)

Further interconnectors are planned in the North-South Interconnector and the ISLES projects. These expansions would bring the Irish interconnector capacity to a total of 6.7 GW.

In addition to these plans, two private companies, Element Power and Mainstream Renewable Power have proposed separate plans to connect wind farms in Ireland directly to the GB national grid via private transmission networks and private HVDC undersea lines. As these systems will not be connected to the Irish network (at least not initially) these will not be considered further in this report.

2.3.1. North South Interconnector

A proposal has been submitted regarding a 400kV interconnector that would run from Co. Meath in the ROI to Co. Tyrone in NI. This would be the second high-capacity electricity interconnector between the two networks, the first of which has been discussed in section 1.7. (Eirgrid, 2011)

2.3.2. ISLES Project

The ISLES project proposes two interconnection zones, Northern ISLES and Southern ISLES, which would connect 2.8GW and 3.4GW respectively of generating resource and interconnection capacity by 2020. This target according to the executive summary is ambitious but achievable. (Scottish Government et al., 2011)

The Northern ISLES concept would connect multiple offshore resources on the south west coast of Scotland and additional resources on the north coast of NI and the ROI. The concept infrastructure consists of a multi-terminal offshore high-voltage direct current (HVDC) backbone running down the west coast of Scotland, and comprises of a number of interconnected 500MW and 1000MW HVDC links, utilising VSC HVDC technology. There is a single dominant connection point at Hunterston in GB with a maximum capacity of 2.5GW. There are also two connection points in Coolkeeragh and Coleraine in NI. The Northern ISLES concept is predicated on the proposed embedded Western HVDC link, without which the ability to export power to Hunterston may be compromised. (Scottish Government et al., 2011)

The Southern ISLES concept in contrast to the Northern ISLES concept comprises predominantly near-shore generation development. The ROI's onshore transmission network, however, has limited coastal network capacity. This means that simple point-to-point links will require significant lengths before reaching a suitable onshore connection location. Therefore the Southern ISLES concept can provide an export path for the identified offshore generation as well as providing beneficial reinforcement of the onshore transmission network. The infrastructure comprises a multi-terminal offshore HVDC backbone running down the east coast

Supported by INTELLIGENT ENERGY EUROPE

of Ireland and includes a number of interconnected 500MW and 1000MW HVDC links, utilising VSC HVDC technology (Scottish Government et al., 2011).

2.4. National Energy Plans for the Future

2.4.1. Plans to 2020

The Irish Renewable Energy Action Plan (NREAP) forms the basis for renewable energy policy in Ireland. It sets out the Government's strategic approach and concrete measures to deliver on Ireland's overall 16% target of energy consumption from renewable energy resources under Directive 2009/28/EC. The Government has set a target of 40% electricity consumption from RES, 10% for transport and 12% renewable heat by 2020 (DCENR, 2010). Already in 2010 the main contribution from renewable resources came from wind power. The projections made for the NREAP show that this will still be the case in 2020. In January 2012 the Irish Department of Communication, Energy and Natural Resources (DCENR) published its first progress report on the Irish NREAP. Some significant changes in projections can be found in light of new information. For example, projections for 2020 in biomass contribution are expected to increase from 153 MW (original estimate) to 274 MW in view of the introduction of a new REFIT scheme for biomass technologies. Wind energy will still provide the bulk of renewable energy in Ireland in 2020, however it is now expected that 3,521 MW instead of 4,649 MW of installed wind capacity will be required to reach the NREAP targets. A summary table is provided in Table 3.

Figure 11 depicts the change in energy mix that is forecasted between 2010 and 2020. The updated figures from the 1st progress report on NREAP have been used.

Table 3: Summary table of the original projections versus the updated projections regarding the ROI's installed capacity for electricity production to meet the Irish 2020 targets.

NREAP: Grid Connection Generation Capacity [MW]						
	2010[1]	2010[2]	2016[1]	2016[2]	2020[1]	2020[2]
Hydro	234	234	234	234	234	234
Wave	0	0	0	0	75	75
Wind	2088	1421	3172	2697	4649	3521
Biomass	77	47	140	213	153	274
Total	**2399**	**1702**	**3546**	**3144**	**5036**	**4029**

[1] *NREAP*
[2] *1st progress report on NREAP*

Eirgrid and Soni, the TSO's for Ireland and Northern Ireland jointly publish the "All-island Generation Capacity Statement" (AIGCS) on an annual basis. The most recent report forecasts the generation capacity from 2013-2022 (EirGrid and SONI, 2012b). Table 4 summaries EirGrid's and SONI's estimates for renewable generation capacity in Ireland to 2020. Slight differences are to be found between Table 3 and Table 4, the most obvious being that wave energy is forecasted in the NREAP but not in the AIGCS. This is because EirGrid has taken a conservative approach to marine energy in that there will not be any commercial marine developments operational by 2020. Nevertheless, the changes in the electricity generation mix between 2010 and 2020 are substantial.

Figure 11 shows data taken from EirGrid and SONI's AIGCS's. The standout differences are wind and thermal; wind will account for twice the electricity production in 2020 whereas thermal energy account for 20% less.

Table 4: Summary table of Installed Capacity from 2010 to 2020 for RES in ROI. Source: (EirGrid and SONI, 2010, EirGrid and SONI, 2011, EirGrid and SONI, 2012b)

EirGrid and SONI: Grid Connection Generation Capacity in ROI [MW]											
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Hydro	237	237	237	237	237	237	237	237	237	237	237
Wave	0	0	0	0	0	0	0	0	0	0	0
Wind	1538	1629	1642	1938	2138	2413	2687	2962	3237	3511	3786
Biomass	48	56	59	85	109	134	153	172	190	209	228
Total	**1823**	**1922**	**1953**	**2275**	**2499**	**2799**	**3092**	**3386**	**3679**	**3972**	**4266**

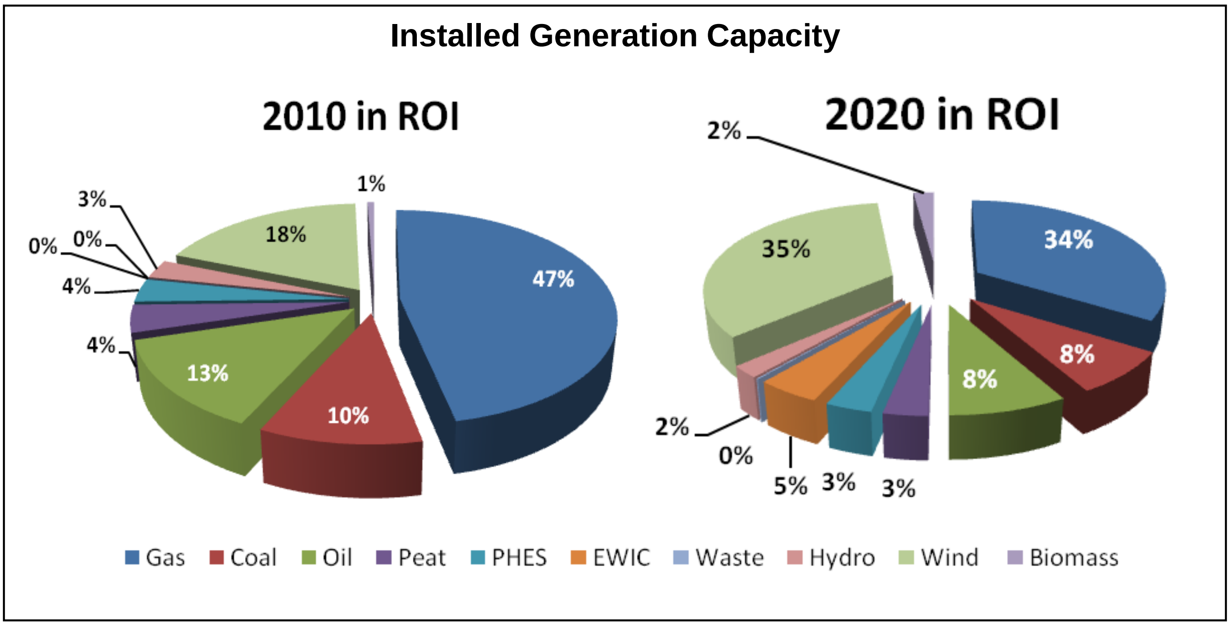


Figure 11: Current (2010) and forecasted (2020) installed generation capacity for ROI. Source: (EirGrid and SONI, 2010, EirGrid and SONI, 2011, EirGrid and SONI, 2012b)

The situation of RES and electricity mix shown by EirGrid and SONI for NI is quite similar to that in the ROI. The main difference is that the overall installed capacity is less due to the difference in population size. Table 5 summaries the AIGCS regarding RES in NI and Figure 12 shows the expected changes in electricity mix from 2010 to 2020 in NI.

Table 5: Summary table of the Installed Capacity from 2010 to 2020 for RES in NI. Source: (EirGrid and SONI, 2010, EirGrid and SONI, 2011, EirGrid and SONI, 2012b)

EirGrid and SONI: Grid Connection Generation Capacity in NI [MW]											
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Hydro	3	4	4	4	4	4	4	4	4	4	4
Tidal	1	1	1	1	1	1	1	1	51	131	154
Wind	380	405	467	550	627	710	790	867	940	1063	1275
Biomass	19	19	23	26	33	56	79	102	107	111	116
Solar	0	0	2	2	2	2	2	3	3	3	3
Total	403	429	497	583	667	773	876	977	1105	1312	1552

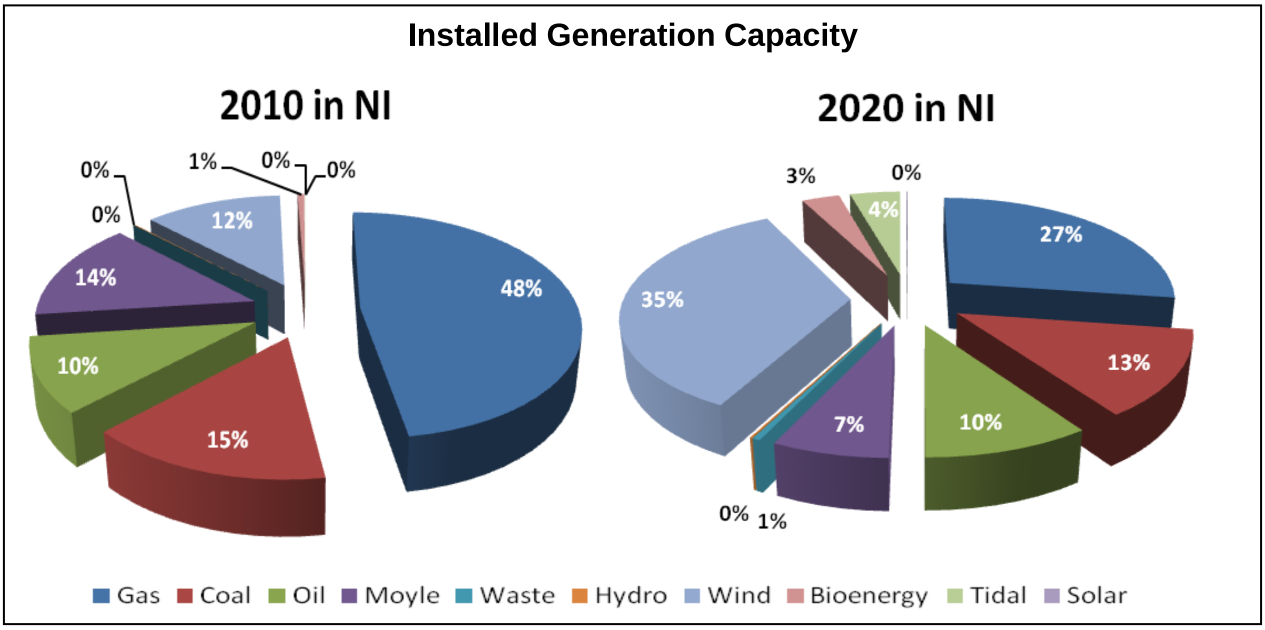


Figure 12: Current (2010) and forecasted (2020) energy mix regarding electricity generation capacity for NI. Source: (EirGrid and SONI, 2010, EirGrid and SONI, 2011, EirGrid and SONI, 2012b)

2.4.2. Energy Roadmap to 2050

In 2011 the Sustainable Energy Authority of Ireland published six energy roadmaps to 2050; Wind Energy Roadmap (SEAI, 2011c), Bio Energy Roadmap (SEAI, 2010a), Electrical Vehicle Roadmap (SEAI, 2011a), Ocean Energy Roadmap (SEAI, 2010b), Residential Energy Roadmap (SEAI, 2010c) and Smartgrid Roadmap (SEAI, 2011b). The roadmaps were developed alongside each other and certain assumptions were made consistently throughout

Supported by INTELLIGENT ENERGY EUROPE

including but not limited to a significant increase in Irish electricity demand to 2050 driven by population growth and increased electrification of residential and service sector. The roadmaps build on the work of the International Energy Agency and identify possible barriers and constraints to increased deployment, and estimates CO2 reduction, value of generation, and job creation benefits.

Wind Energy Roadmap

Due to Ireland's significant wind resources Ireland could contribute 2.5% to EU Electricity Demand and just over 5% of EU wind energy generation. Onshore, Ireland's wind resources represent some of the most effective renewable resources in Europe and offshore it benefits from Ireland's extensive area of offshore territory in the Atlantic and the Irish Sea. Furthermore, onshore and offshore wind energy represents a significant carbon abatement opportunity, whereby wind could abate between 400 and 450 MT of CO2 by 2050.

SEAI have calculated that Ireland can achieve deployment of 11 GW to 16 GW onshore and 30 GW offshore wind energy by 2050. Subsequently, this means that Ireland has the potential to generate enough electricity from wind energy to exceed domestic demands by 2030 (SEAI, 2011c).

Bioenergy Roadmap

Bioenergy is a resource that can be used in heat, electricity and transport. SEAI has calculated that by 2020, the main contribution from biomass electrical generation will be co-firing and waste to energy. It estimates a total generation capacity of 580ktoe/yr. By 2050, biomass in Ireland should generate 28% of total electricity demand totalling almost 2000ktoe/yr.

Electric Vehicle Roadmap

Transport accounts for one third of Ireland's energy requirements and energy related CO2 emissions and is almost entirely dependent on oil. In 2011 there was a total private car stock of 1,887,810 cars in the ROI (DTTAS, 2011). With a population of 4,588,252 in the same year (CSO, 2013), this means that on average there is 1 car per every 2.5 persons.

The EV within this roadmap includes battery electrical vehicles (BeV) and plug-in hybrid electrical vehicles (PHEV). The Roadmap assumes that by 2020 the contribution from EV to the passenger car segment is 10% (according to the Irish NREAP) and that by 2050 the mean EV deployment will amount to 60%[5]. EV deployment causes gross electricity consumption to increase by 14%. Depending on the amount of hours electricity is consumed at night determines the electrical capacity required. One of the main issues will therefore be EV load management to minimise grid development costs. The Roadmap also points towards EV demand assisting in managing wind variability.

Ocean Energy Roadmap

According to this Roadmap, ocean energy in Ireland has the potential to reach 29 GW of installed capacity without likely significant environmental effects. One scenario suggests that there will be 1500MW of ocean energy by 2030.

Residential Energy Roadmap

This Roadmap sets out several different scenarios, "Baseline measures", "Improved Building Regulations", "Low", "Medium", "High Electricity" and "High Fuel". These scenarios have been applied to calculate Irelands total residential energy demand forecasting between 2010 and 2050. Noteworthy is that the "Baseline measures", which reflect current national and EU regulations will increase Irish total energy demand, whereas all other scenarios decrease at

[5] 18% of car will be driven by H2 Fuel Cells, and the rest will be new ICE cars.

Supported by INTELLIGENT ENERGY EUROPE

different rates. This Roadmap clearly shows that the “Baseline measures” is not an option if CO_2 targets and energy targets are to be met.

Smartgrid Roadmap
By 2050 the final electrical demand will be in excess of 48,000GWh with a corresponding peak demand of 9GW. Onshore wind generation will be able to supply up to 33,000GWh of the total demand.

Increasing the electrification of thermal load in the residential and service sector will see an annual demand in this sector in excess of 28,000 GWh by 2050.

By 2025 Ireland will have 1.4 GW of interconnection (according to Grid 25). The analysis made in this Roadmap estimates that a further 1.6 GW of interconnections will be required by 2040.

2.5. Energy Storage Development Plans

Currently (2012) there is only one significant electrical storage facility on the grid, the pumped hydro energy storage (PHES) facility at Turlough Hill in the Wicklow Mountains. It was commissioned in 1974 and can generate up to 292MW. The topography of Ireland is characterized by gently sloping and not particularly high mountains compared to other countries. Therefore there has been a low development of hydropower but also PHES historically (EirGrid, 2009).

Energy storage technologies, particularly PHES, are gaining momentum as one possible solution to help abate curtailment from wind (Foley et al., 2013). Different studies show different levels of wind curtailment in Ireland. The study by EirGrid and SONI (2012a) show that already 2.2 % of wind generation in the ROI and NI (119 GWh) in 2011 was dispatched down due to system curtailment or local constraints. By 2020, EirGrid and SONI (2012b) report that wind curtailment will reach 4 %; elsewhere a figure of 6 % is presented (O'Sullivan, 2012). The study by Mc Garrigle et al. (2013) in contrast show that anywhere between 7 and 15 % wind curtailment could occure in 2020. One study by EirGrid (2009) has carried out a cost analysis of the potential benefit of PHES; showing that up 40 % RE share would result in low levels of curtailment. However, the study focuses more on the economic benefit of PHES rather than the benefit of PHES to the grid.

In 2011 Turlough hill was unavailable due to extensive maintenance works and it is notable that during this time higher levels of curtailment was reported than would otherwise have been expected.

Although the NREAP and the latest DCENR report on Strategy for Renewable Energy: 2012-2020 (2012) recognize that large scale storage facilities merits attention, specifically PHES and CAES, no overall plan seems to exist yet for these infrastructures. Nevertheless, there has been a recent interest in building closed-loop and semi-open PHES systems (Wänn et al., 2012), due to the suitable rolling hill landscape and the extensive cliff coastline which may be suitable for sea water PHES.

Regarding development plans, a connection agreement has been signed for a 70MW PHES facility in Co. Cork. The PHES will use the already existing Inniscarra reservoir as the lower reservoir and an upper reservoir will be constructed on the nearby hill. Inniscara dam together with Carrigadrohid dam are collectively known as the Lee hydro scheme and belong to the ESB group which was commissioned in 1957 with a total installed capacity of 27MW.

Glinsk seawater PHES is a project proposed by Organic Power (Organic Power Ltd, 2011a, Organic Power Ltd, 2011b). The site is located on the west coast in County Mayo, Ireland.

Supported by INTELLIGENT ENERGY EUROPE

Glinsk Mountain is a flattop mountain, very much like the already existing Okinawa seawater PHES in Japan. The project proposes an installed capacity of 960 MW with a storage capacity of 6 GWh. The idea is that the PHES will act as an Energy Storage Hub that will use excess electricity from the surrounding wind energy and future wave energy during off peak hours to pump water from the sea to the reservoir. The electricity generated from wind and the PHES will be transported via HVDC cables across Ireland to the Woodland 400kV Station that will feed into the East West Interconnector. The project however has been waiting for the go ahead for a number of years now. In March 2012 a statement was issued that An Board Pleanala[6] have only given a preliminary view that this project is deemed to be of strategic importance but that a final decision will be made in the near future (The Mayo Today Editor, 2012).

CAES opportunities are also being explored on the island of Ireland. The geology of Larne Co. Antrim in NI is believed to have the potential to support CAES, as large salt deposits in the rock could be leeched out to create appropriate caverns. Gas fields, such as those at Kinsale, could also be potential CAES sites once the gas reserves have been fully exhausted. The existing knowledge and infrastructure at such sites would simplify any potential developments. (EirGrid, 2009)

It may also be worth noting that PHES and CAES are large infrastructural projects involving major civil, mechanical and electrical engineering works. Thus, it may take up to 15 years from project inception, development to commissioning. The main reasons for this time span are: lack of consideration and testing at strategic planning level; lack of experience in developing these projects in the current regulatory environment; and limited ability and resources of competent authorities, particularly on a local level, to evaluate these large and often complex projects (Wänn et al., 2012).

[6] An Board Pleanala is the Irish national planning authority

Supported by INTELLIGENT ENERGY EUROPE

3. Reference and Future Development Scenarios

Two scenarios for RES development are explored in this Chapter.The first concerns the year 2020, when, according to the Irish NREAP the RES share in electricity production will reach 40%. Reliable data is available till 2020 and it is therefore possible to state how much energy storage will be needed to reach the NREAP targets. For this purpose three different cases have been investigated, A, B and C, where each of these investigates different levels of RE shares in the system by varying the total amount and the amount of installed capacities from onshore and offshore wind.

The second scenario investigates the impact on the electric power system with a RE share of 80%. This scenario was chosen to specifically avoid restriction to a specific year. No studies were found that clearly forecasted for 2050 and it was therefore difficult to estimate the development of RE after the year 2020. This second scenario uses data from the NREAP and scales them accordingly. The cases in this scenario investigate a RE share of 80 % in an isolated system without energy storage, with energy storage and with interconnections which allow for export and import. An overview of these scenarios and the installed power of each technology can be found in Table 6.

Table 6 Overview of the scenarios investigated for the estimation of future energy storage needs

RE power plants	Ref.*	2020 Scenario (in MW)			80% Scenario (in MW)		
		A	B	C	A	B	C
Wind (onshore)	1655	4094	4000	4200	9200	Import/export investigations	
Wind (offshore)	25	555	100	600	3900		
Photo voltaic (PV)	0	0	0	0	0	0	0
Hydropower	237.7	238			238		
Other RES	1.1	1.1			1.5		
Yearly peak load	4.64	5.87			7.87		
Load demand in TWh	25.8	32.71			45		
RE production (TWh)	4.25	13.08	11	14	36		
RE share	16.5%	40%	33.6%	42.8%	~80%		

**Reference year data from 2011*

Notes regarding data used in the modelling

Bioenergy is regarded as controllable combined heat and power (CHP) plant and is therefore not listed; wind feed-in curves were downloaded from EirGrid for the year 2011; and for the import/export investigations a simplified model of the British electricity supply system was modelled where generation data per fuel type and net electricity consumption were downloaded from the ELEXON portal for the year 2011 and the installed capacity are based on the UK Renewable Energy Strategy[7] for the year 2020 and then scaled accordingly to reach a total renewable energy share of 80% of the net electricity consumption.

3.1. *Residual Load and Rejected Energy without Energy Storage*

The residual load (RL) is defined as the load demand minus the production from non-controllable renewable energy sources. In other words, the RL is the part of the load demand that may need to be covered by controllable power plants (fossil or renewable), import/export of energy or energy storage. For Ireland therefore, the RL is defined as the load demand minus

[7] Presented to Parliament by the Secretary of State for Energy and Climate Change, July 2009. Can be downloaded and seen at http://www.official-documents.gov.uk/document/cm76/7686/7686.pdf

wind power production minus non-controllable part of hydropower. In this way a positive RL indicates a level of load that needs to be covered by either conventional or controllable renewable power plants, imports or energy recovered from storage facilities. In the same way then, a negative RL indicates that there is a surplus of fluctuating energy that either needs to be stored, exported or curtailed.

The rejected energy is the energy from fluctuating renewable sources that cannot be integrated onto the grid. This does not take into account energy storage or import and export of energy. In other words, it is the energy that is initially rejected if there is no energy storage systems or transmission lines (or interconnectors) to neighbouring countries.

Synchronous generation units help the grid to maintain a constant supply of frequency, whereas non-synchronous do not. This is because the majority of wind turbines are connected indirectly to the grid via power electronic converters to operate with a variable rotational speed to better adapt to different wind conditions. Other non-synchronous generators are: tidal turbines, marine wave devices, photovoltaic (PV) and HVDC imports.The TSO's therefore impose limits on the instantanoues proportion of system load that can be served by non-synchronous generators. All additional non-synchronous generation has to be rejected (curtailed), or if possible, stored or exported (Mc Garrigle et al., 2013).

If excess wind energy is to be stored or exported it must be balanced with extra synchronous generation to keep the non-synchronous penetration limit (SNSP). The result therefore is that for a SNSP limit of for example, 75 %, once that limit is reached, every extra 75 MW of wind energy that is to be stored or exported must have an extra 25 MW generation capacity from a synchronous generator so that the SNSP limit is not exceeded. Thisrequirement could be circumvented by e.g. hybrid wind farm-energy storage facilities which share the same grid connection point (e.g. offshore wind farms and sea water PHES), thereby allowing surplus wind generation to be stored without the use of the grid.

For the 2020 scenario a SNSP limit of 75 % is envisaged. This means that at least 25 % of the load has to be covered by generation units that are directly connected to the grid and are operating at the grid frequencey.

For the 80 % scenario an SNSP of 100 % was used as it was assumed that by the time a RE share of 80 % is reached, the transmission and distribution grids will be stable and flexible enough to manage 100 % load coverage by renewable, non-synchronous generation.

A summary of the results for the 2020 scenario and the 80 % RE scenario can also be found in Table 7.

Table 7 Summary of the results analyzing the residual load and rejected energy for scenarios A,B,C and 80% RE

Scenario	Max. power below penetration limit	Rejected Energy w/o storage
A	1,466 MW	473.23 GWh
B	934 MW	139.32 GWh
C	1,589 MW	585.27 GWh
80 % RE	7,064 MW	7,729.30 GWh

3.1.1. 2020 Scenarios

Already in 2020, the RL (red) in the ROI is negative some of the time (see Figure 13 and Figure 14) for all three cases, which means that there is a surplus of fluctuating renewable energy that either needs to be exported, stored or curtailed. As expected case C shows a negative RL for more time and thus a higher surplus of electricity than the two other cases. Although the

Supported by INTELLIGENT ENERGY EUROPE

differernce is not that great because the three cases are fairly similar in RE shares and the only RES that is varied is wind power.

A further observation that can be made in Figure 13 is that the load (black) fluctuates less than the RL (red) for both the ROI and GB. Moreover, the spread between maximum and minimum in th RL is higher. This indicates that there will be a need for very flexible production units that can cover the high levels of fluctuations.

In GB the residual load stays in the positive the whole year, so the RE production never exceeds the load demand. Depending on the flexibility of the British system there could be enough capacity to export the surplus of RE from the island of Ireland to GB.

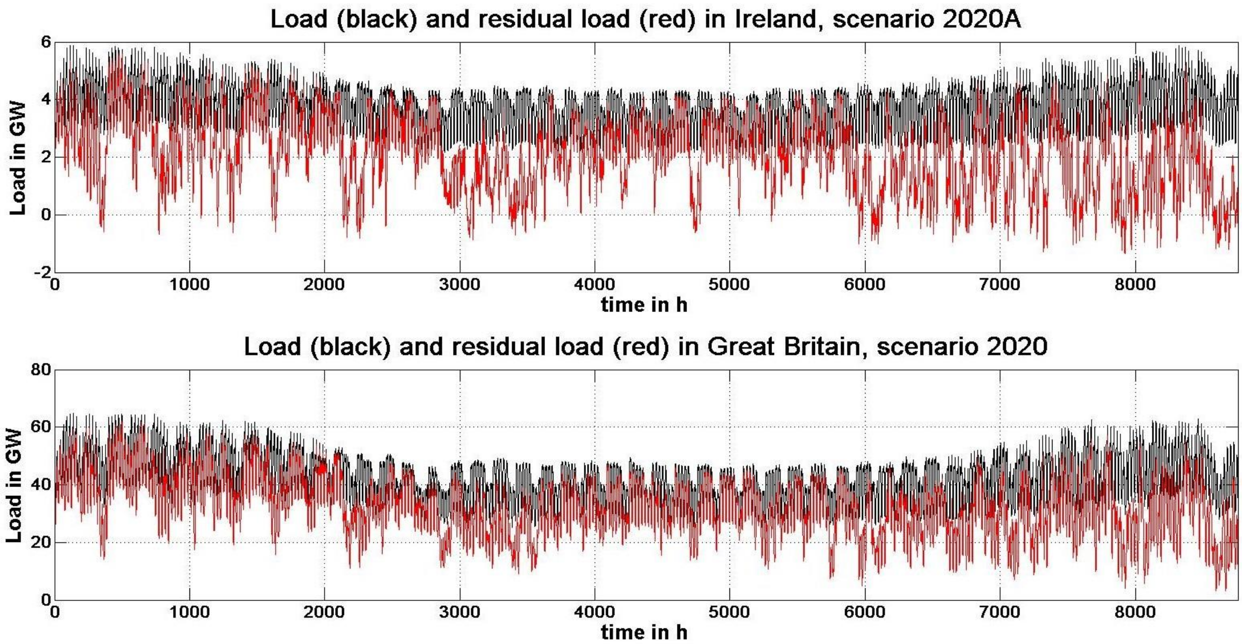


Figure 13: Load demand (black) and residual load (red) in Ireland (above) and Great Britain (below) for the scenario 2020 A in Ireland and the basic 2020 scenario in Great Britain

Figure 15 shows the negative RL as rejected energy instead. As previously determined case C shows the most negative RL and therefore also the highest level of rejected energy with a total of 585 GWh. Case A is calculated to have a total rejected of 473 GWh and Case B has the lowest amount of rejected energy with 139 GWh.

The same ranking can be observed with the highest power below the SNSP, implying that there is a higher level of renewable energy than the system stability allows for (see Figure 15 and Table 7): 1,589 MW in scenario C, 1,466 MW in scenario A and 934 MW in scenario B.

Supported by INTELLIGENT ENERGY EUROPE

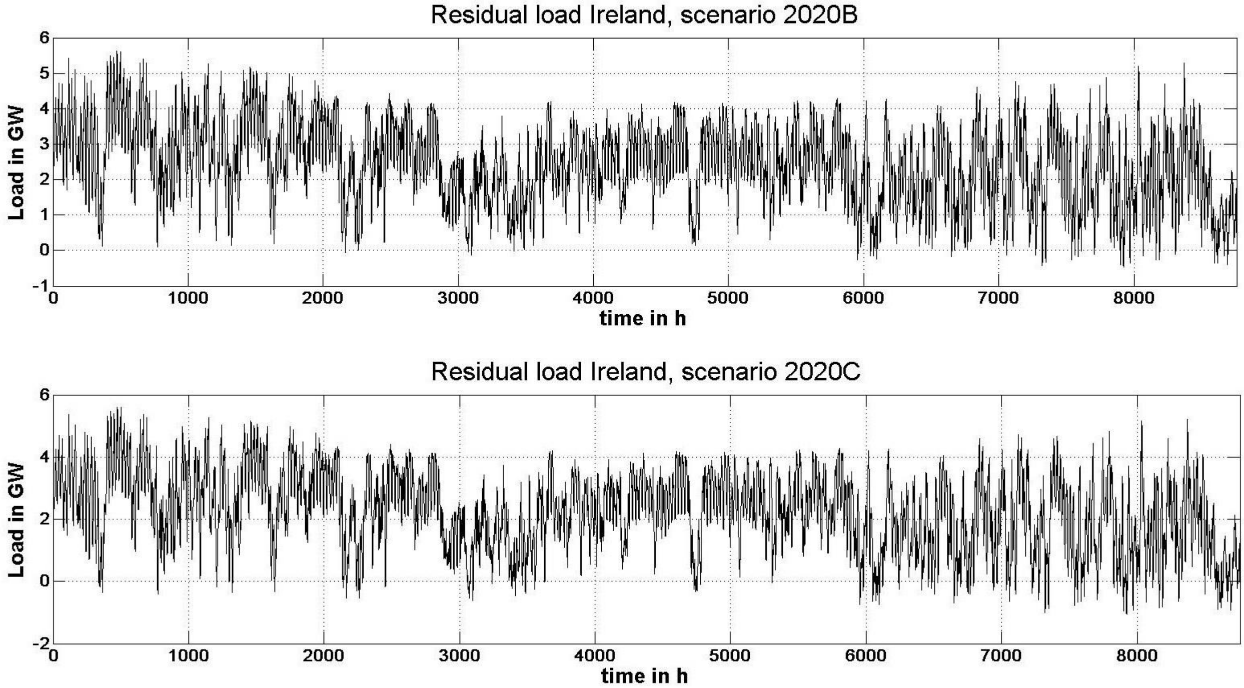


Figure 14: Residual load in Ireland for the scenarios 2020 B and C

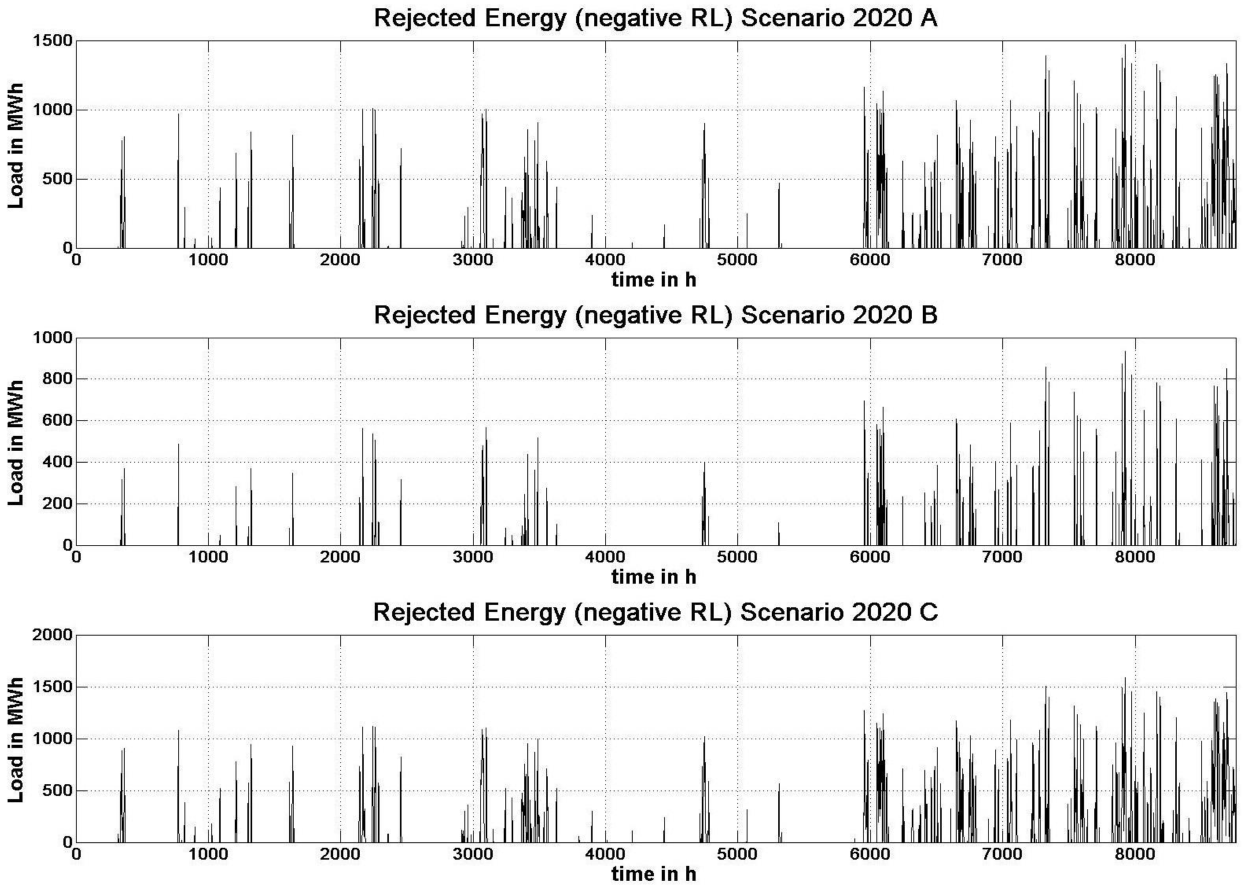


Figure 15: Rejected energy at hourly value for the full year, scenarios 2020 A,B,C (from top to bottom)

Supported by INTELLIGENT ENERGY EUROPE

3.1.2. 80 % Renewable Energy Scenario

In the 80 % scenario, the RL (red) is often negative for long periods of time (from multiple hours up to days). This is especially the case at the end of the year during a surplus of long and strong wind energy (see Figure 16). This surplus will either need to be exported, stored or curtailed.

The load (black) in the 80 % scenario is similar to that in the 2020 scenarios, however, the RL (red) has increased significantly; especially the spread between maximum and minimum. The magnitudes of both the maximum and minimum RL values are similar.

The same characteristic can be observed in the British system. The residual load reaches negative values of more than 50 GW (see Figure 16). There is also a period of strong surplus at the end of the year.

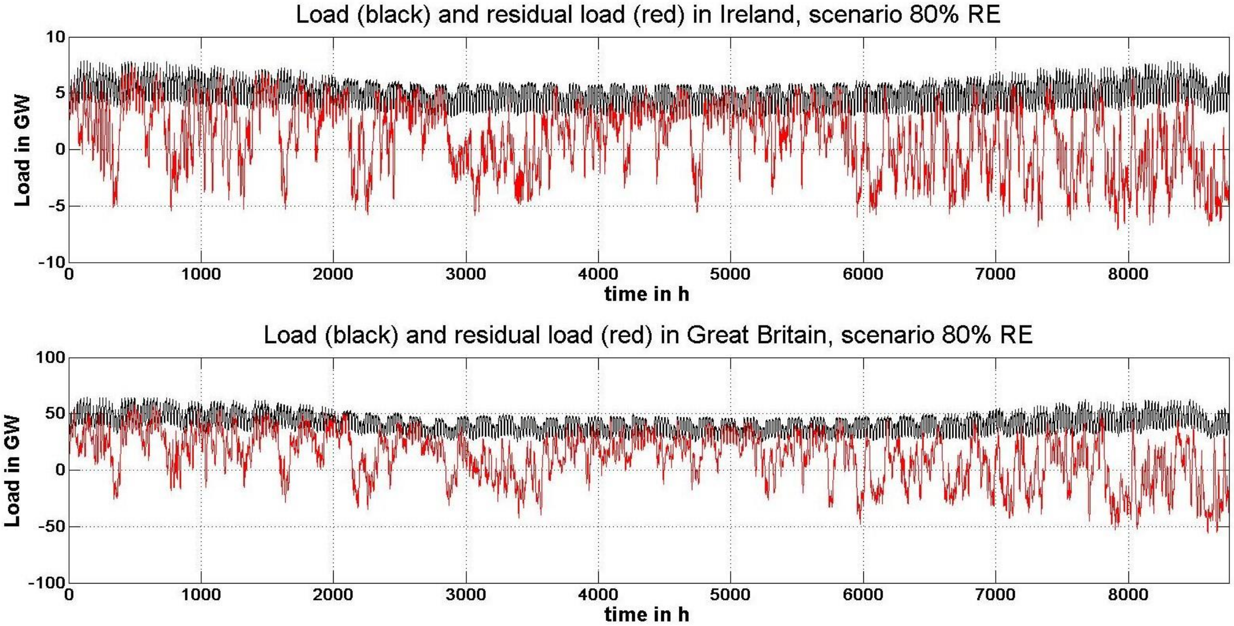


Figure 16: Load demand (black) and residual load (red) in Ireland (above) and Great Britain (below)

Figure 17 shows the same result but in the form of rejected energy instead. It can be clearly seen that the highest level of rejected energy is in the second part of the year, during autumn and winter, with rejected energy levels reaching 7.7 TWh. This is already 22 % of the predicted feed-in from renewables in this scenario.

Supported by INTELLIGENT ENERGY EUROPE

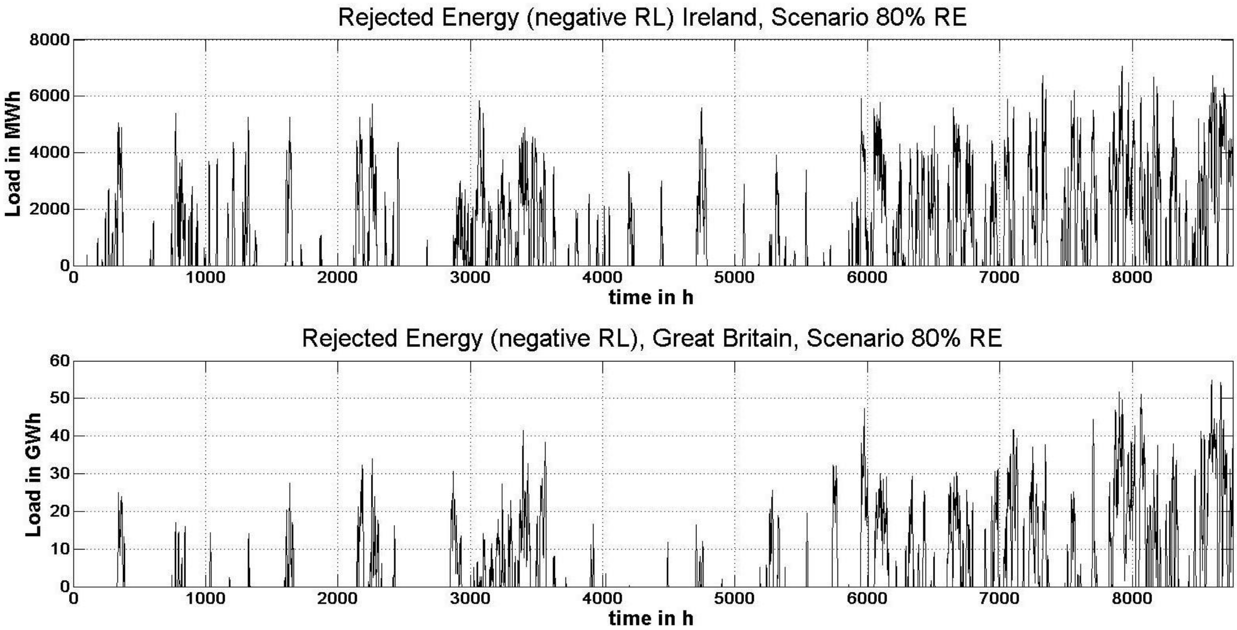


Figure 17: Rejected energy at hourly value for the full year for the scenario 80% RE in Ireland (above) and Great Britain (below)

3.2. Load Variations

The variation in GW per 1 hour / 3 hours / 8 hours is shown in Figure 18. The variation of the load is shown in black bars whereas the variations of the residual load are plotted in lines (Case A: red, Case B: green, Case C: blue). This plot estimates the flexibility needed in an electricity system. The x-axis shows the variation in GW/time in negative as well as in positive direction whereas the y-axis shows the occurrence per year. For example, diagram (a) shows the variation in GW/1h, at 0 shows an occurrence of 2500 per year. This means that at almost 2500 hours per year the load varies less than 1 GW per hour. The maximum variation here is -0.8 GW/h on the negative side and 1.2 GW on the positive side.

Due to higher fluctuations of the residual load (see Figure 13 and Figure 14) there are fewer times the residual load varies by less than 1GW/h. At the same time the maximum variation increases. The effect of an increased load variation can be observed fairly well for a variation time of 3 and 8 hours (diagram (b) and (c)). In this range it can be seen that the maximum and minimum variation magnitude variations increase. 3 and 8 hours have been chosen because it is the range of warm and cold start times of coal fired units which are often used as base load units and with rising share of renewables have to operate more often in part load or even have to be shut down completely for a certain time. Strong load fluctuations have thus to be covered by fast reacting units like gas turbines. This again indicates that the electricity system will have to become more flexible to be able to adapt more quickly to high load variations in a positive as well as negative direction.

Supported by INTELLIGENT ENERGY EUROPE

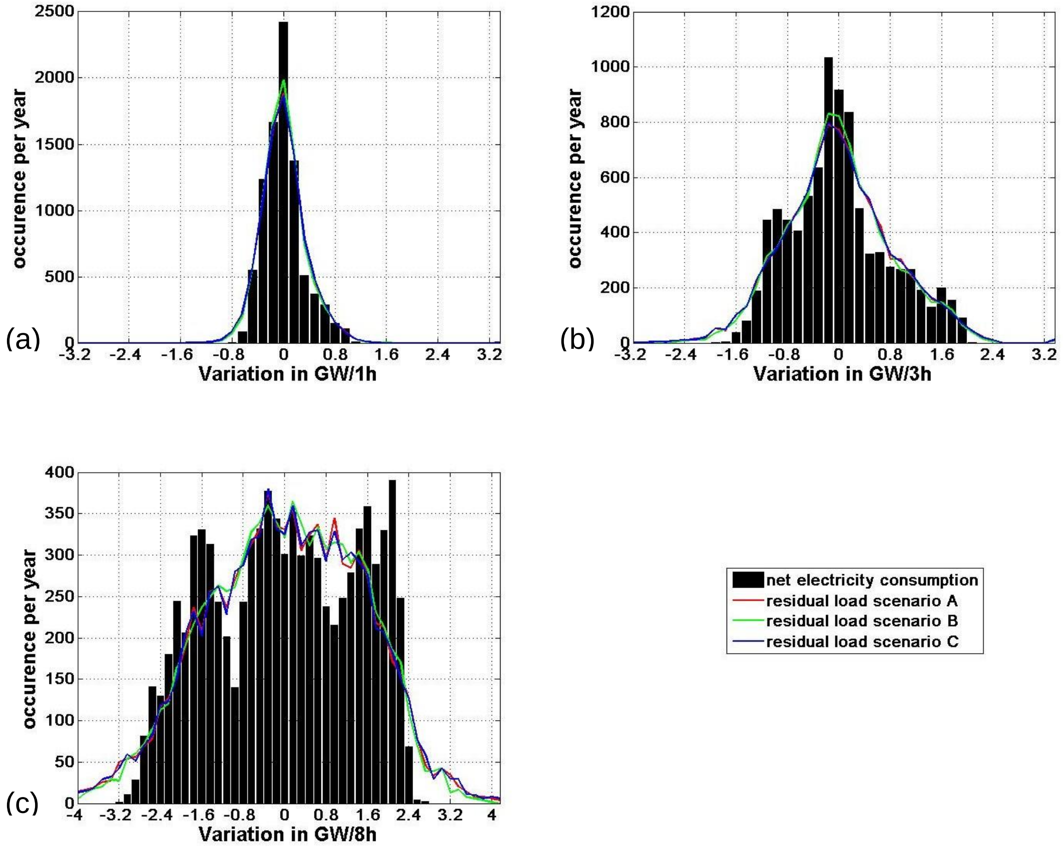


Figure 18: Load variation of consumption (black bars) and residual load of scenario A (blue), B (red) and C (green)

4. Energy storage needs for future development scenarios

This chapter explores the impact of energy storage on the two scenarios, 2020 Scenario and 80 % RE Scenario. To recap, the data for each scenario is provided in Table 8. The calculated results show the total need for energy storage capacity should no wind curtailment take place. It should be noted that the results are only of theoretical value. The available sites for PHES development in Ireland are limited, especially in terms of GWh storage capacity, and it would not be practically or economically possible to construct this type of scenario. Nevertheless, it is useful to study as it represents the upper bounds of what is possible with energy storage.

Table 8 Overview of the scenarios investigated for the estimation of future energy storage needs

RE power plants	Ref.*	2020 Scenario (in MW)			80% Scenario (in MW)		
		A	B	C	A	B	C
Wind (onshore)	1655	4094	4000	4200	9200	Import/export investigations	
Wind (offshore)	25	555	100	600	3900		
Photo voltaic (PV)	0	0	0	0	0	0	0
Hydropower	237.7	238			238		
Other RES	1.1	1.1			1.5		
Yearly peak load	4.64	5.87			7.87		
Load demand in TWh	25.8	32.71			45		
RE production (TWh)	4.25	13.08	11	14	36		
RE share	16.5%	40%	33.6%	42.8%	~80%		

**Reference year data from 2011*

To determine the energy storage needs, an algorithm has been developed at the Helmut-Schmidt-University to estimate the energy storage needs from a system point of view. The aim of the energy storage facilities in this approach is to integrate the maximum renewable energies possible without any focus on the electricity spot market price. During times of positive RL the energy storage system (ESS) is used to smoothen the RL. Before the RL turns negative, the algorithm will attempt to discharge the energy storage system completely to ensure that maximum integration of wind power is possible.

To calculate the overall energy storage needs two ESS are integrated in the computation algorithm. The first technology is the already existing energy storage systems plus any expected expansion of energy storage system. This means that for the ROI the existing energy storage system (technology 1) consists of the existing PHES system, Turlough Hill.

The second technology has an unlimited capacity and power and is not linked to any specific storage technology. Technology 2 can take the surplus of renewable energy that cannot be stored by the existing system (Turlough Hill). Due to its unlimited power and capacity, technology 2 enables the full integration of all renewable energies. The actual used power and capacity of this second technology is an indicator of the required additional energy storage capacity.

4.1. *Residual Load and Load Variation with Energy Storage*

4.1.1. 2020 Scenario

Figure 19 show the residual load after the use of energy storage systems (ESS) for the scenarios A, B and C. The residual load is smoothened and no more negative peaks appear as compared to the results shown in Chapter 3.1.1 where the electricity system had no energy storage. All energy below the penetration limit can be absorbed by the ESS and no more wind energy is rejected. This is due to the unlimited nature of technology 2 which can store all the energy that cannot be stored by Turlough Hill.

The maximum residual load is lowered by 1 GW to 4.5 GW in each scenario. The minimum load that has to be covered by conventional and controllable renewable production units is now ~0.8 GW.

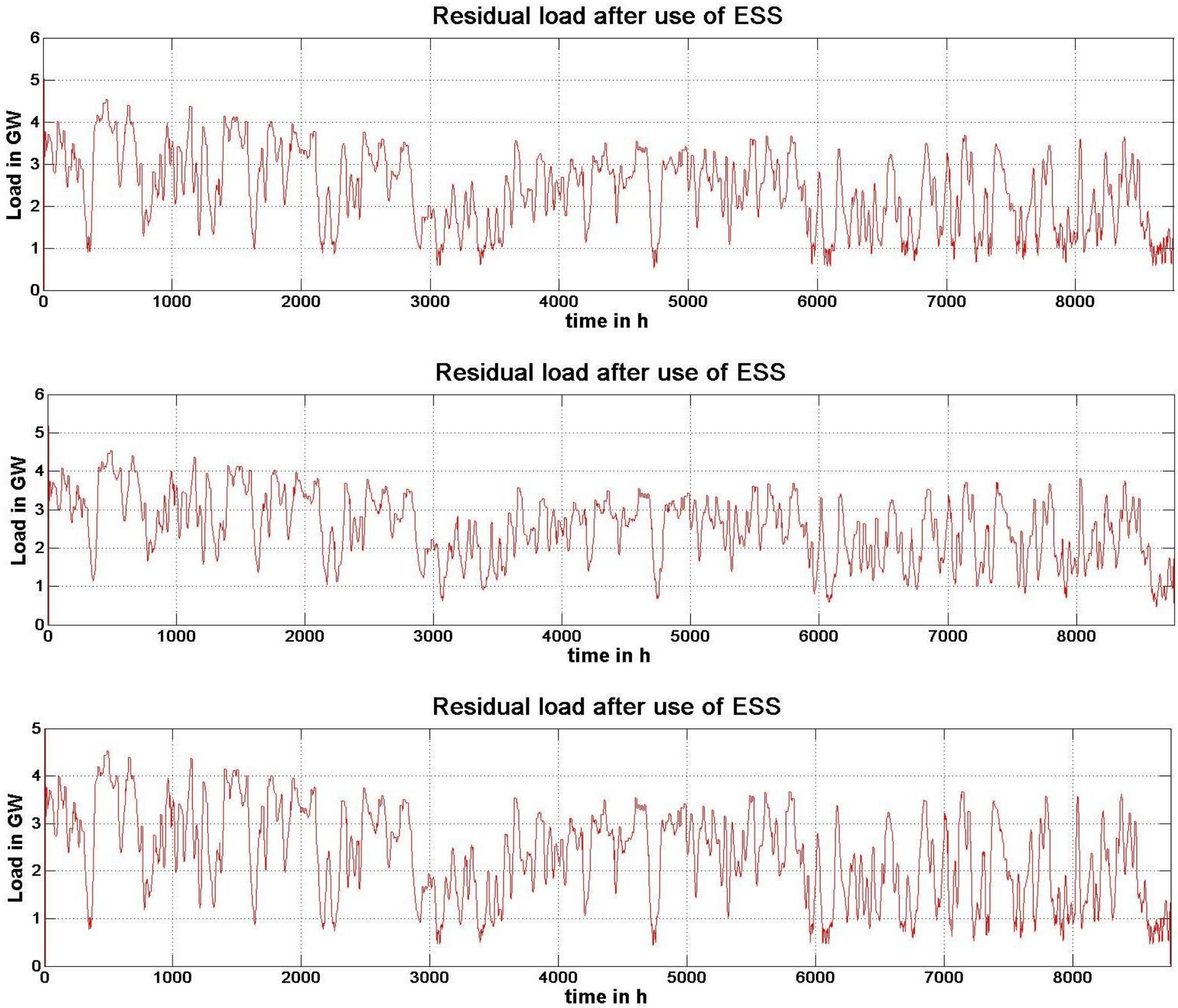


Figure 19: Residual load taking into account energy storage systems in Case A, B and C (from top to bottom)

Figure 20 the operation of the PHES system during hours 4000 to 5000 for Case A. Negative values demonstrate that the facility is in discharging mode and positive values show the PHES in charging mode. It can be seen that the PHES system is frequently charged and discharged completely and the is often used as well. The plots for Case B and C are almost identical to Case A and are not dealt with in the text; however, these can be found in the Annex.

The capacity factors for case A, B and C are all around 60 % which is exceedingly high (Table 9). This is due to the fact that there is no participation on the electricity market modeled. In

Supported by INTELLIGENT ENERGY EUROPE

many cases the operation during positive residual load hours would not be economic. But as the storage facility is operating from a system point of view only, it is used to balance as many fluctuations as possible to enable an easier and more flexible operation management of the conventional, hydro or controllable renewable power plants.[8]

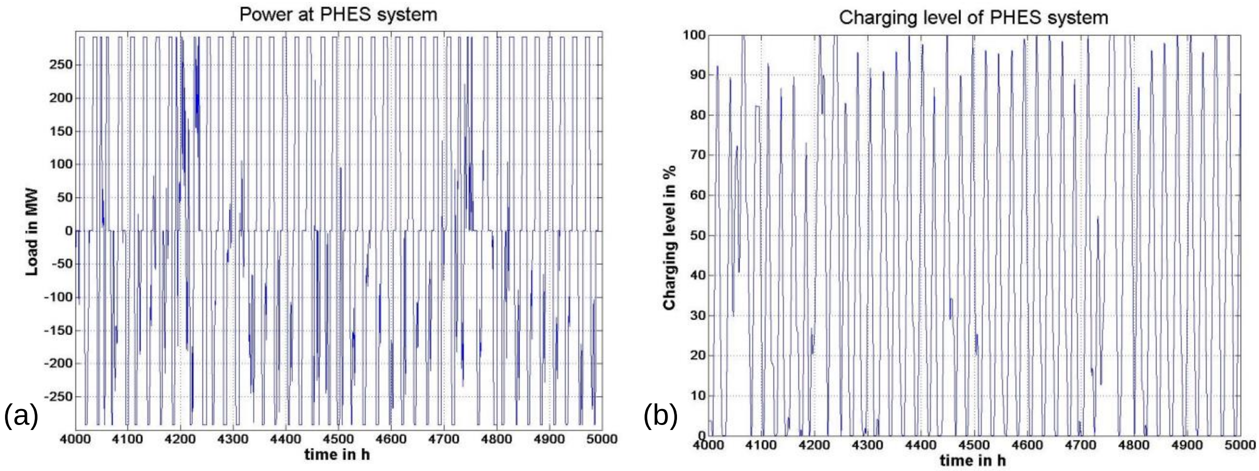


Figure 20: A zoom on the hours 4000 to 5000 for a more detailed view of PHES operations. Power (a) and charging level (b) of the PHES system for scenario 2020 A.

Figure 21 show the needed power and capacity of technology 2 in cases A, B and C respectively. In both case A and C the influence of strong wind penetration at the end of the year can already be observed. The storage system cannot discharge because the residual load stays below the SNSP limit. There is another period in autumn after hours 6000 where the energy system is filled to a high extent but can be discharged again afterwards due to a longer period of lower wind feed-in. The needed capacity of technology 2 to fully integrate all wind energy is calculated to 59 GWh in scenario A and 70 GWh in scenario C. This does not take into account possible wind curtailment or export possibilities. Export may lower these storage needs if the British or NI system is flexible enough to take these surpluses (see Chapter 4.2).

The effect described cannot be observed in scenario B. Technology 2 is used for RL smoothening most of the year and the surpluses of wind energy by the end of the year and around hour 6000 are not over any longer period of time. Therefore, the reservoir can always be emptied and allows for a lower storage capacity of 14.32 GWh.

The needed power of technology 2 is more or less the same in each scenario. Furthermore there is not much difference in the charging and discharging power used. It is the lowest in case B (1.73 GW charging / 1.60 GW discharging power). The highest charging power is in case C (1.86 GW) whereas the highest discharging power is in case A (1.79 GW). Table 9 and Table 10 summarizes the results from this Chapter.

[8] This is currently how PHES is being operated in many power systems.

Supported by INTELLIGENT ENERGY EUROPE

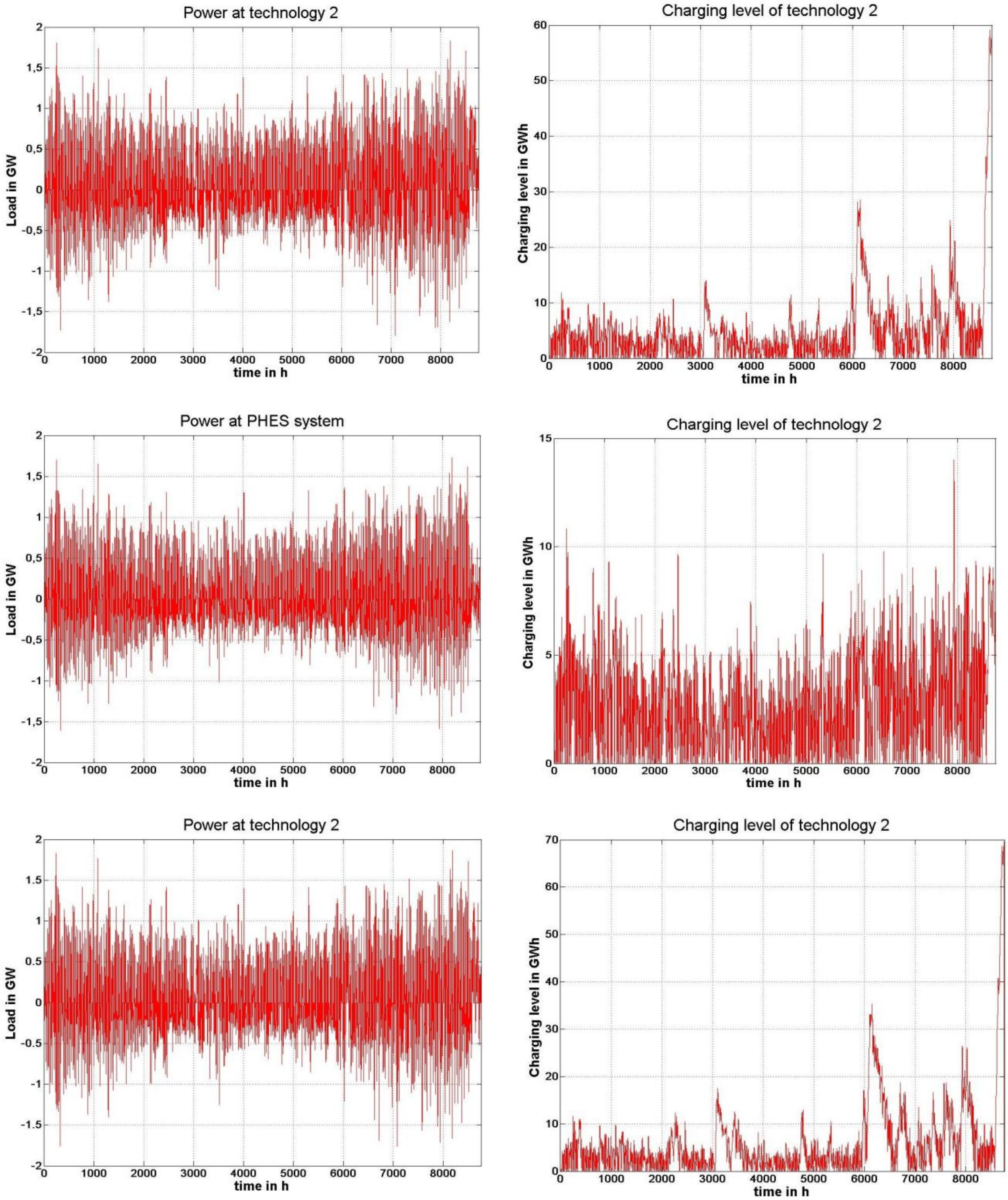


Figure 21: Power (left) and charging level (right) of technology 2 for Case A (top), Case B (middle) and Case C (bottom)

Figure 22 shows the load variations after the use of the energy storage system. Figure 22 shows the load variations after the use of the energy storage system for Scenario 2020 A. It can be seen that the load has been smoothened in comparision with the results in Chapter 3.2; especially high load fluctuations have been filtered out for the time horizon of 3 and 8 hours respectively. The load variations of less than 1 GW are much higher for all three spans. This

Supported by INTELLIGENT ENERGY EUROPE

enables the conventional, hydro or controllable renewable power plants to react more easily to load fluctuations and also the shutdown of a slow starting power plant can be handled.

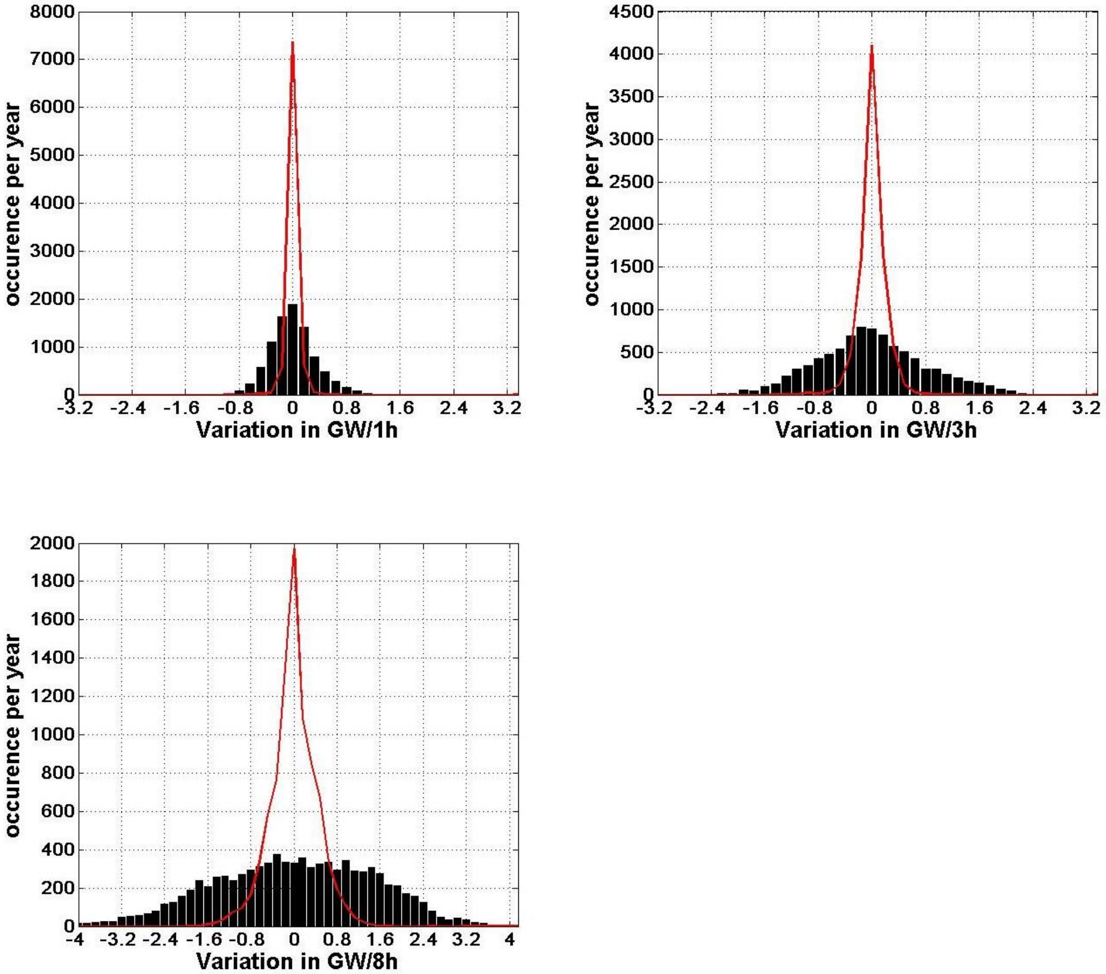


Figure 22: Load variations of residual load for Scenario 2020 A before (black bars) and after (red line) use of ESS

Table 9 Overview of results analysing PHES system operation in scenarios 2020 A, B and C

Summary of PHES operation (Technology 1)					
	Energy		Capacity factor		
	Stored (GWh)	Provided (GWh)	Charging	Disch.	Total
A	846.91	705.40	33.15%	27.61%	60.76%
B	850	707.29	33.23%	27.64%	60.87%
C	848.87	684.97	33.19%	26.78%	59,97%

Supported by INTELLIGENT ENERGY EUROPE

Table 10 Energy storage capacity and power requirements under different cases of RES-E mixes within the 2020 scenarios

	Energy Storage System (Technology 2)				
	Needed Power (GW)		Needed capacity (GWh)		
	Charging	Discharging			
A	1.83	1.79	59.12		
B	1.73	1.60	14.32		
C	1.86	1.76	70		
	Energy		**Capacity factor**		
	Stored (GWh)	Provided (GWh)	Charging	Disch.	Total
A	1790.66	1394.02	11.17 %	8.89 %	20.06 %
B	1604.44	1293.80	10.59 %	9.23 %	19.23 %
C	1753.80	1373.18	10.76 %	8.91 %	19.67 %

4.1.2. 80% Renewable Energy Scenario

The PHES system (technology 1) is not used as much in the 80 % scenario as in the 2020 scenarios. The capacity factor in the 80% scenario is less than half of that in the 2020 scenarios; 24 % compared to roughly 60 %. This is due to the fact that the residual load is negative over longer periods of time so that the PHES system reaches its limits more frequently and cannot discharge directly afterwards; it now has to wait until the residual load is in the positive again.

In the same way as in the 2020 scenario however, the unlimited capacity and power of technology 2 helps achieve that the residual load does not turn negative and all energy from RES can be integrated onto the grid. Figure 23 shows the residual load after the use of ESS for the 80 % scenario.

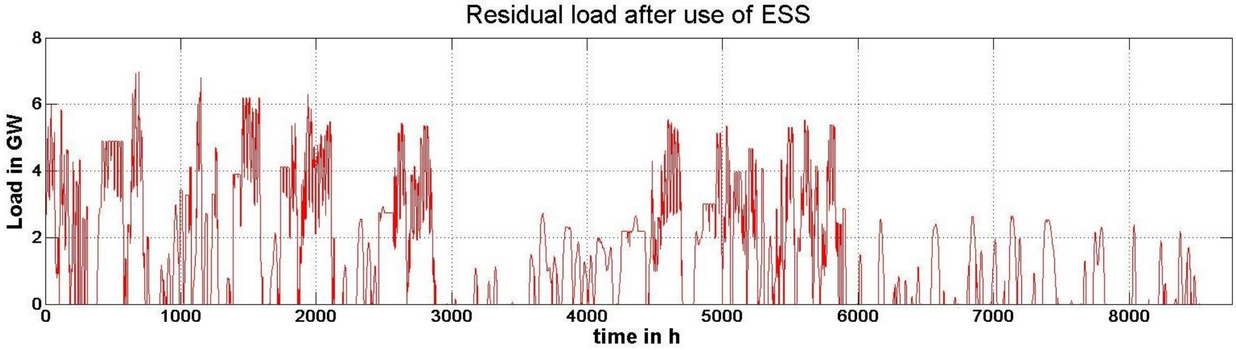


Figure 23: Residual load after use of ESS, scenario 80 % RE

Figure 24 shows the operation of the unlimited technology 2. The problem of the dependency of wind can be observed very clearly. There is a significant feed-in from wind in the second half of the year. This results in an ever rising need for storage capacity towards the end of the year. As can be seen there are low fluctuations within this graph which indicate that there are still discharging cycles but the energy that has to be stored is higher than the energy that can be

Supported by INTELLIGENT ENERGY EUROPE

discharged. For the full integration of all wind energy a total energy storage capacity of 2.77 TWh would be needed. The needed power is now asymmetric. The needed charging power (6.8 GW) is higher than the needed discharging power (4.3 GW). To limit the needed capacity of the ESS, curtailment may be a good option. Another option would be to export, which will be discussed in more detail in Chapter 4.2.

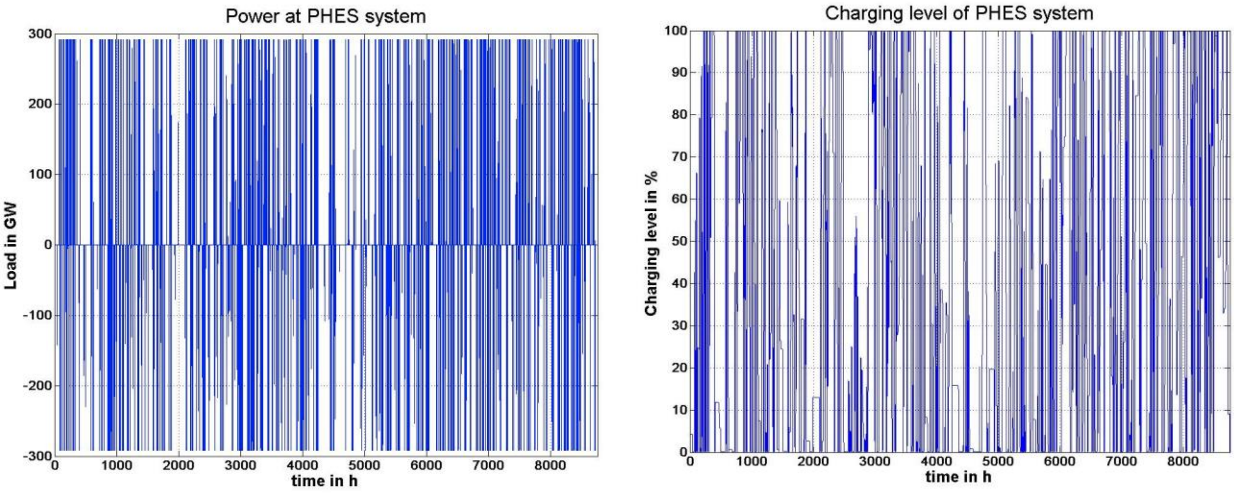


Figure 24: Power (left) and charging level (right) of PHES system, scenario 80 % RE

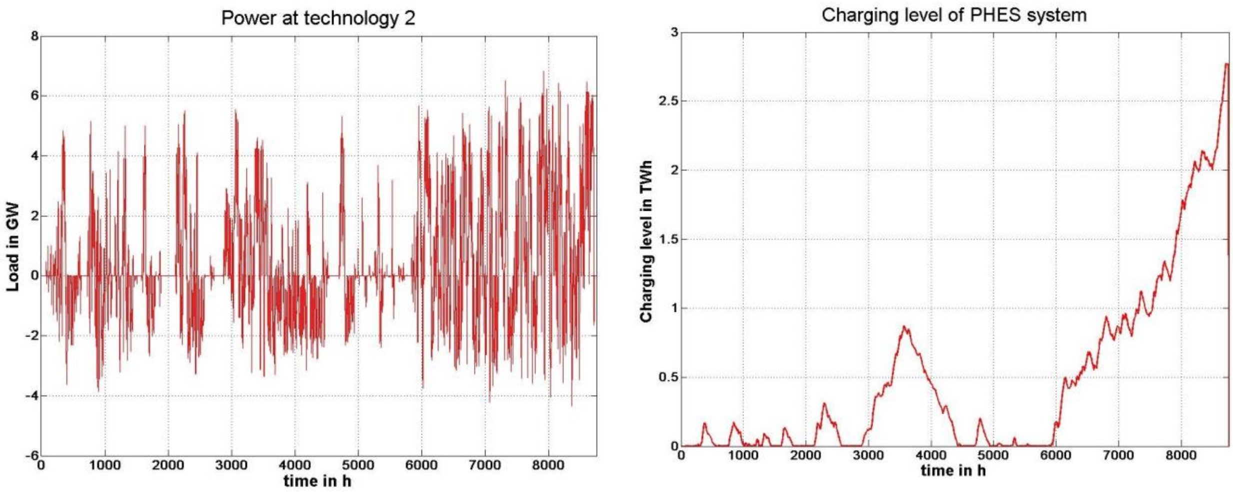


Figure 25: Power (left) and charging level (right) of technology 2, scenario 80 % RE

As the needed capacity is strongly depended on the surplus of wind over a long period of time the question is: does the needed power in charging and discharging mode change if the capacity of the reservoirs is limited? Simulations were therefore made with different storage capacity limits; however, the needed power is still unchanged even with a storage capacity limit of one third that of what was initially needed. Only when using a storage capacity limit of 800 GWh does the required power decrease.

An overview of the results of the 80 % RE scenario can be found in Table 11.

Supported by INTELLIGENT ENERGY EUROPE

Table 11 Overview of storage requirements under the 80% RE scenario

Summary of ESS operation					
	Energy		Capacity factor		
	Stored (GWh)	Provided (GWh)	Charge	Disch.	Total
PHES	339	274.5	13.3 %	10.7 %	24.0 %
Tech 2	7388	3743	12.4 %	9.9 %	22.3 %
Needed power and capacity of Technology 2					
	$P_{max, charging}$	$P_{max, discharging}$	E_{max}		
	6.8 GW	**4.3 GW**	**2.7 TWh**		

4.2. Rejected Energy with Energy Storage and Interconnections

4.2.1. Correlation between Wind Power in Ireland and Great Britain

For the correlation of wind the wind data for the 80 % RE scenarios for ROI and Great Britain were investigated. The data is based on the real feed-in curves from wind in both countries in the year 2011.

The cross-correlation factor was calculated with equation 1, whereby $\rho(\tau)$ is the correlation factor, x(t) and y(t) are the signals that are compared and τ is the shift factor.

$$\rho(\tau) = \lim_{T\to\infty} \frac{1}{2T} \int_{-\infty}^{\infty} x(t)y(t+\tau)dt \qquad (1)$$

For the calculations in this report the two signals that are compared are the wind production in Ireland and Great Britain. For quality reasons the two time series are normalized before calculating the correlation factor. This way the influence of the amplitudes of the two signals is filtered out. As the time series are in hourly values and the period of investigation is one year, there are 8760 measured data for each signal. This means that τ will run from -8759 to 8759. This way a correlation factor for each time difference will be calculated and it can be seen at which time lag the wind production of the ROI and GB correlates the most.

Figure 26 shows the normalized production of wind energy in Ireland and GB and Figure 27 shows the results of the correlation factor of the measured feed-in curves. The time series have been normalized by their corresponding maximum. As can be seen the production of wind in ROI and Great Britain correlate well. This merits further investigation. The maximum correlation factor is 0.914 at a time lag of 4 hours, which means that the maximum correlation of the wind appears 4 hours later in GB after the wind has appeared in Ireland.

The OffshoreGrid project (www.offshoregrid.eu) calculated the correlation coefficient between the UK and Ireland to be 62 % with 0 lag time for a 2030 scenario including offshore wind (De Decker and Kreutzkamp, 2011), while Foley et al. (2009) estimated a 2-3 hour lag between peak wind speeds in ROI and GB.

Supported by INTELLIGENT ENERGY EUROPE

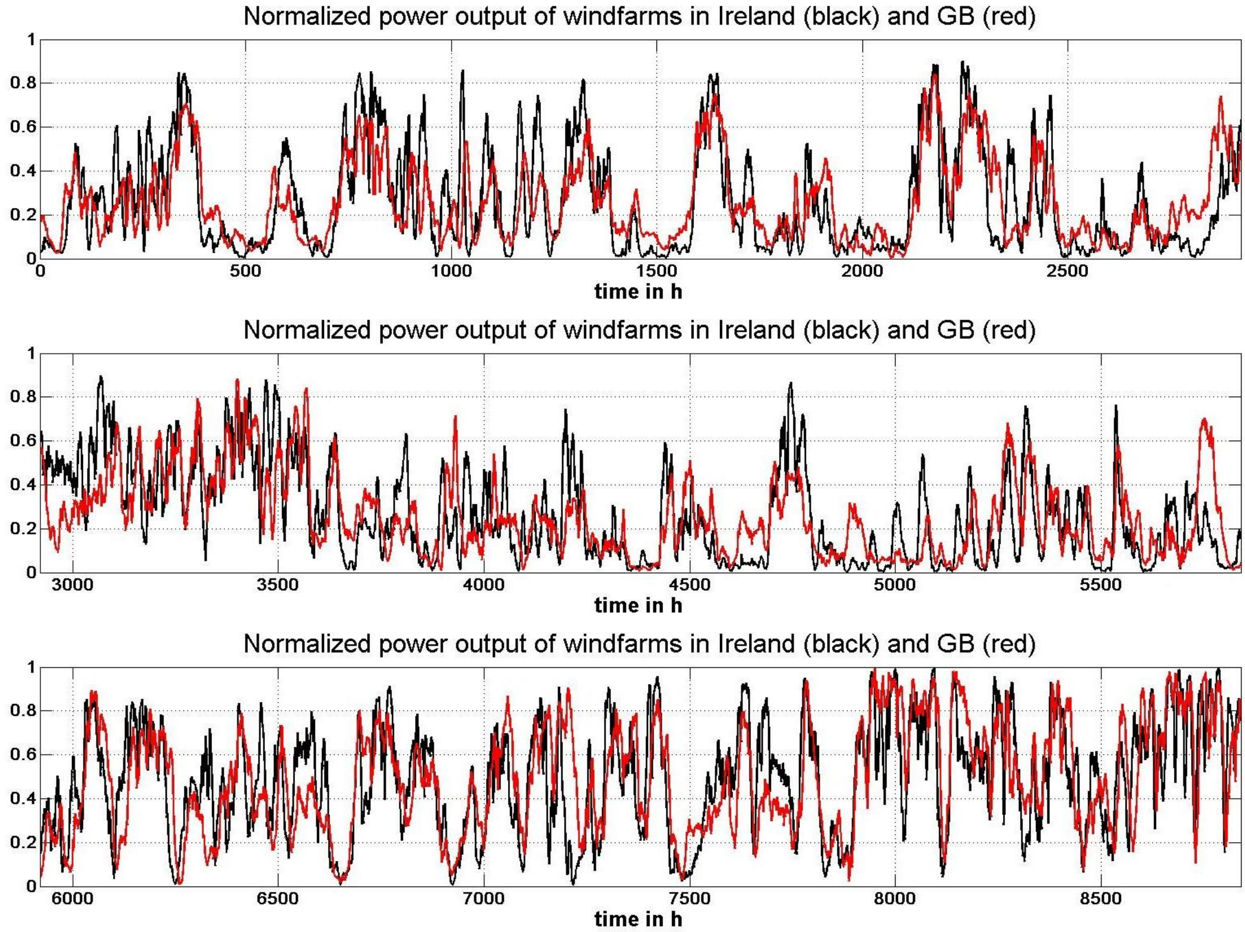


Figure 26: Normalized wind energy production in Ireland (black) and Great Britain (red)

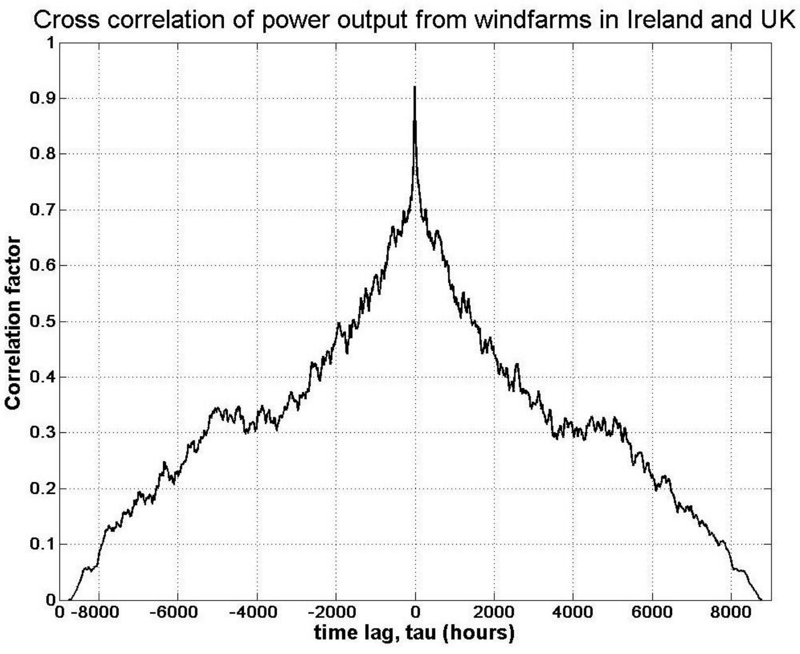


Figure 27: Correlation factor of wind production in Ireland and Great Britain as a function of time lag (tau)

4.2.2. Transmittable Energy with different interconnection capacity

In this section the influence of HVDC connectors from the ROI to GB is investigated. This scenario was chosen to show that neither energy storage or transmission capacity extension alone is the solution to integrating a high share of RES in the ROI. Both measures will be needed and are important. The results will show that export of energy will not always be possible because there is a high time correlation of renewable energy production between the ROI and GB.

Figure 28 illustrates the results of the investigations made for an interconnection capacity of 2 GW. The first image shows the rejected energy in Ireland without interconnectors, the second shows the rejected energy with interconnectors and the third shows the transmitted energy through these interconnectors. There is not much difference between the first two images; this is particularly clear towards the end of the year, when there is high feed-in from wind power. The same issue can also be observed in the image of transmitted energy. The interconnectors are not in use for large extents of time, especially from hour 7500 to the end of the year; this is due to two reasons:.

Reason1: There is no surplus of renewable energy in the Irish system and thus there is no need to export energy from a system point of view. This may change if the electricity market is taken into account as well. It may be more economic e.g. to export the energy to GB (if needed there) than to shut down a base load unit. Furthermore the interconnectors could also be used to import energy!

Reason2: There is a surplus of renewable energy in the Irish and in the British system so that there is no possibility to transmit the energy because it cannot be used in the British system.

Additionally it can be observed that the interconnectors are most of the time either fully used or not used at all. Nevertheless there are some restrictions regarding the capacity factor of the transmission line, the transmittable energy and use of the interconnectors. As already mentioned the transmitted energy would be different if there was a market model because the energy would also be used during time of positive RL just for energy trading.

A further export to e.g. France through the British system has not been investigated and could further increase the amount of exportable energy. However, this requires that the transmission lines and HVDC interconnectors in and from GB have enough export capacity not only to export its own surplus but the Irish surplus of wind energy as well. Furthermore this requires that the energy is needed in France or other countries that are also connected.

Figure 29 illustrates the results for an interconnection capacity of 1 GW as well as an unlimited interconnector. As can be seen the difference between 1 GW and no limitation is small, which implies that an extensive extension of interconnection capacity would not bring much benefits for the Irish system. However, high-voltage alternating current (HVAC) lines could still bring the benefit of becoming integratred into the larger synchronous system. Given that the dominant interconnector technology is currently HVDC this is unlikely to happen in the near future.

Investigations would need to be made in regards to whether or not the transmission of excess wind energy to the European mainland would improve the overall situation shown in this Chapter.

All the results are summarized in Table 12.

Supported by INTELLIGENT ENERGY EUROPE

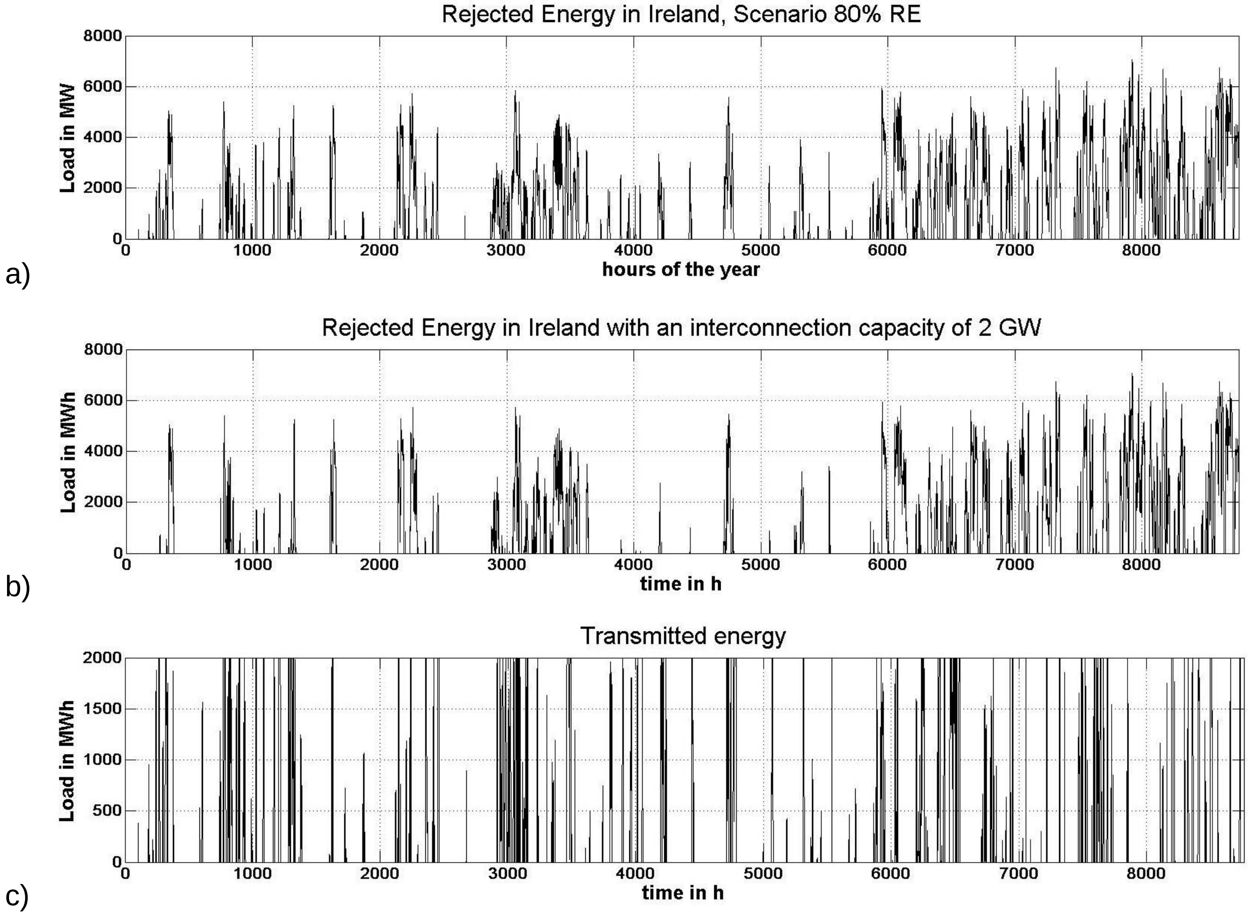


Figure 28: a) Rejected Energy in Ireland as isolated system and b) with an interconnection capacity of 2 GW to NI and Great Britain. c) Rejected energy that is transmitted through interconnections to NI or Great Britain.

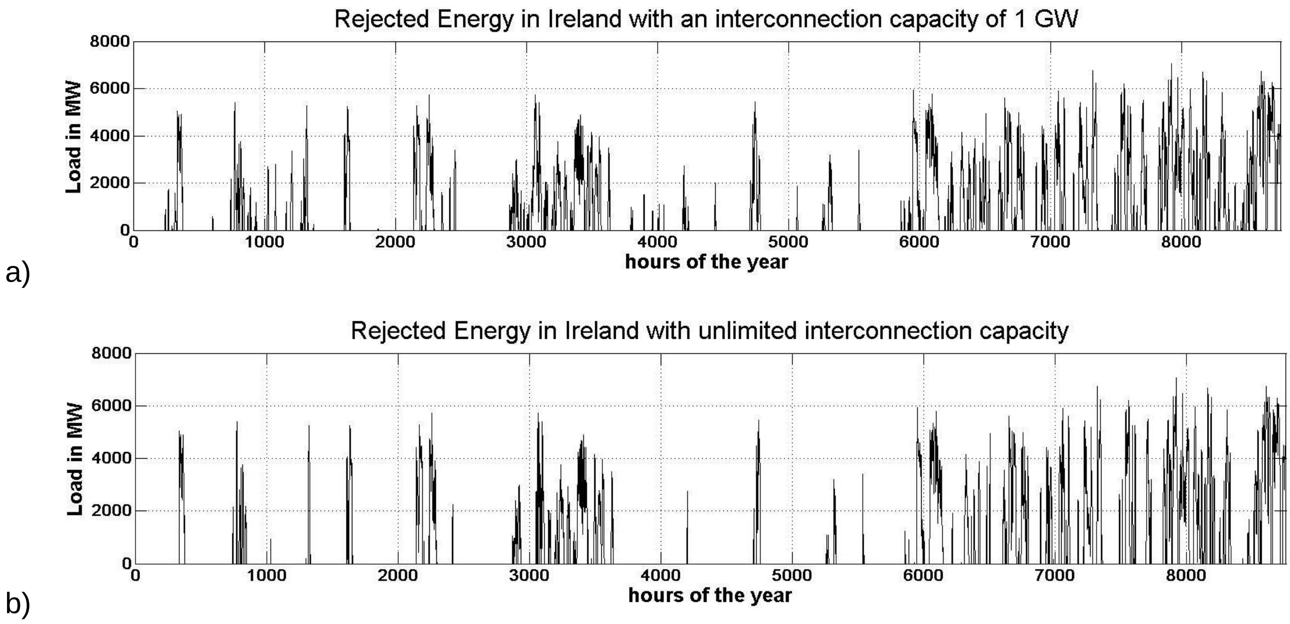


Figure 29: a) Rejected energy in Ireland with an interconnection capacity to Great Britain and NI of 1 GW and b) an unlimited unlimited interconnection capacity to Great Britain and NI

Supported by INTELLIGENT ENERGY EUROPE

Table 12 Influence of interconnection capacity on rejected and transmitted energy

	Interconnection capacity			
	None	1 GW	2 GW	Unlimited
Rejected Energy	7,729 GWh	6,695 GWh	6,122 GWh	5,744 GWh
Transmittable Energy	0 GWh	1,029 GWh	1,603 GWh	1,981 GWh

4.2.3. Influence of Interconnection capacity on calculated energy storage needs

Figure 30 and Figure 31 shows the needed power and capacity of technology 2 for the ROI where the interconnection capacity has been taken into account. For this purpose the two highest values for the interconnector have been chosen: 2 GW and no limit.

One of the main observations in Figure 31 as well as in the summary of the outcomes in Table 13 is that the needed power in charging as well as in discharging mode stays the same. This is due to the fact that during the period of the highest surplus of wind energy the same effect also appears in GB. The needed storage capacity only decreases slightly. The stored and provided energy decreases much more, since energy that would have been stored and provided at a later time is now transmitted. This, in combination with the same need for power ((as without interconnection) results in a lower capacity factor in charging as well as discharging mode. This results in a lower overall capacity factor, so that the overall economic efficiency is lowered as well.

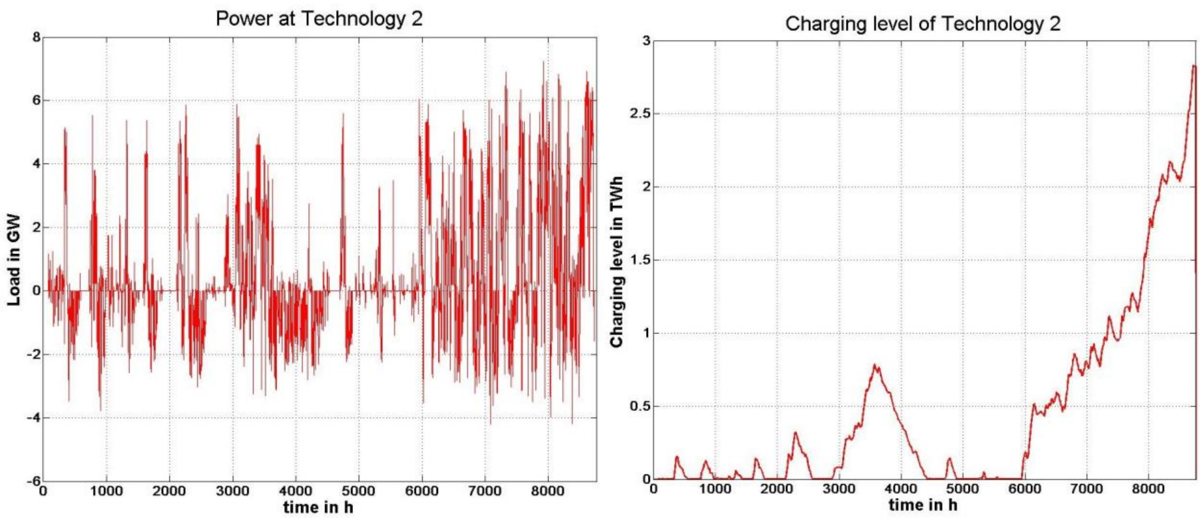


Figure 30: Storage needs with integration of 2 GW interconnection capacity to Great Britain

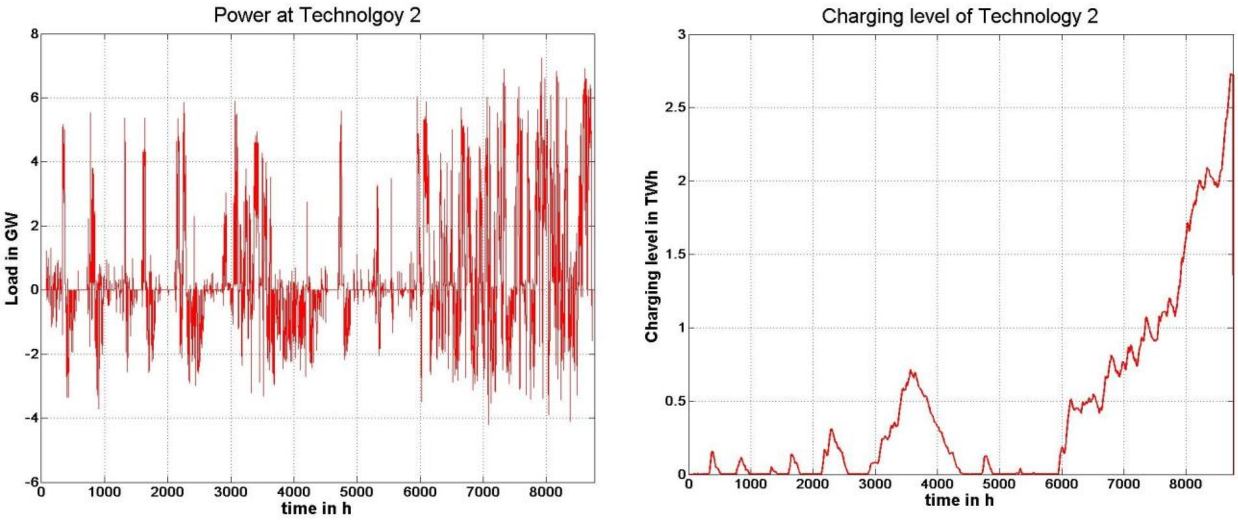


Figure 31: Storage needs with integration of unlimited interconnection capacity to Great Britain unlimited

The interconnectors transmit the energy that would otherwise have been used for storage, especially short term storage like PHES. This can be seen by the fact that when including interconnector capacity in the simulation the capacity factor of Turlough Hill is reduced. On the other hand interconnectors cannot handle surpluses due to longer periods of strong wind because this high level of wind generation is likely to occur simultaneously in both jurisdictions, ROI and GB. An overview of the outcomes of the simulation can be seen in Table 13.

Table 13 Influence of interconnection capacity on ESS operation and size

Interconnection capacity	1 GW	2 GW	unlimited
E_{stored}	7,246 GWh	6,686 GWh	6,326 GWh
$E_{provided}$	3,505 GWh	3,128 GWh	2,917 GWh
E_{max}	2,769 GWh	2,725 GWh	2,711 GWh
$P_{max, charging}$	6.8 GW	6.8 GW	6.8 GW
$P_{max, discharging}$	4.3 GW	4.3 GW	4.3 GW

Supported by INTELLIGENT ENERGY EUROPE

Summary and Conclusions

The aim of this report is to determine the need for bulk energy storage capacity in the Republic of Ireland (ROI) by investigating future development plans for the year 2020 and also an 80 % renewable energy share penetration. Furthermore, this report considers the impact of interconnector capacity to Great Britian (GB).

As interconnections to GB and Europe are presently weak, the island of Ireland can be described as an “isolated grid”. Furthermore, due to a large stock of thermal generating units the Irish grid is also “centralised”. There is however, some flexibility in the system due to several peaking plants (gas turbines) and the pumped hydro energy storage (PHES) unit Turlough hill.

The island of Ireland is heavily dependent on fossil fuel for power generation. The ROI recently commissioned two new combined-cycle gas turbines (CCGT)and has plans to commission a further 5 CCGTs and one open-cycle gas turbine. These plants can act as peaking plants but will not be of benefit in curtailing surplus wind energy. The current plan in the ROI is to build several new interconnectors to strengthen its grid with (Northern Ireland) NI, to directly feed into the British grid via Wales and also to more easily manage the upcoming offshore and near shore marine and wind energy.

Studies have been made to investigate the value of adding large energy storage systems, such as PHES and compressed air energy storage (CAES). However, at present there are no significant plans in constructing bulk energy storage facilities. Nevertheless, PHES is gaining momentum across Europe and also in Ireland, although development plans are currently mainly developer driven. Investigations have also been made in terms of how much wind will actually be curtailed at different RE shares.

In contrast to previous studies, this report has found that with the anticipated levels of variable renewable energy sources coming online, excess energy can only be abated with the help of interconnectors in combination with bulk energy storage such as PHES.

Wind is the most abundant renewable energy resource in Ireland, therefore two future scenarios were developed based on high levels of wind generation. One scenario is based on the NREAP’s 40% RE electricity target for 2020, and the other examines an 80% RE share. Table 14 shows a summary of the investigate scenarios.

Table 14 Overview of the investigated scenarios

RE power plants	Ref.*	2020 Scenario (in MW)			80% Scenario (in MW)		
		A	B	C	A	B	C
Wind (onshore)	1655	4094	4000	4200	9200	Import/export investigations	
Wind (offshore)	25	555	100	600	3900		
Photo voltaic (PV)	0	0	0	0	0	0	0
Hydropower	237.7	238			238		
Other RES	1.1	1.1			1.5		
Yearly peak load	4.64	5.87			7.87		
Load demand in TWh	25.8	32.71			45		
RE production (TWh)	4.25	13.08	11	14	36		
RE share	16.5%	40%	33.6%	42.8%	~80%		

**Reference year data from 2011*

Supported by INTELLIGENT ENERGY EUROPE

In the 2020 scenario a non-synchronous penetration limit (SNSP) was set to 75 % and for the 80 % RE share a SNSP limit was set to 100%. If excess wind energy is to be stored or exported it must be balanced with extra synchronous generation to keep the SNSP.

Energy Storage needs without Interconnection

The results from the 2020 scenario show that with current development plans (excluding interconnections) the residual load will turn negative some of the time, especially in the autumn and winter months when there is long and strong surplus of wind. As the, instantaneous non-synchronous generation (i.e. most wind generators and HVDC imports) is likely to be limited to a 70-75% proportion of total system demand, with any excess wind generation during these periods to probably be curtailed. PHES or CAES can help address this problem by increasing the effective system load. An additional energy storage capacity of between 13.4 and 70 GWh can help abate the otherwise rejected energy (curtailment).Other possible technical solutions to this problem include the construction of hybrid wind/PHES plants, or wind turbines that can emulate synchronous generators for short periods of time. Similarily, the load variation becomes more managable implying that there is a need for further flexibility in the current electricity grid.
The results from the 80% RE share scenario showed the same tendencies as in the 2020 scenario only in that the grid issues become amplified. The need for storage capacity reaches 2.7 TWh.

It should be noted that the calculated results show the total need for energy storage capacity should no wind curtailment take place. This is only of theoretical value. The available sites for PHES development in Ireland are limited, especially in terms of GWh storage capacity, and it would not be practically or economically possible to construct this type of scenario. Nevertheless, it is useful to study as it represents the upper bounds of what is possible with energy storage.

Influence of Interconnections

To better understand the influence that interconnections may have on the Irish electricity system a correlation factor was calculated for Irish and British wind. The result showed that there is a time lag of approximately 4 hours, which means that it takes 4 hours for the wind to appear in GB after it has appeared in Ireland. The influence of the correlation factor becomes apparent in the results for the need for interconnections.
Two different interconnection capacities were investigated, 2GW and unlimited capacity. The results show very little difference in rejected energy, 6.1 TWh and 5.7 TWh respectively. The high level of correlation between Ireland's wind generation and GB wind generation means that prolonged periods of high exports of surplus wind are unlikely to occur. The pattern of interconnector usage is more likely to be dominated by shorter term fluctuations.

Energy storage needs and Interconnections

The results of simulating the need for energy storage capacity needs in a system that either has 2 GW or unlimited interconnection capacity are very similar to the energy storage needs in a system without interconnection capacity. In both cases an energy storage capacity need of approximately 2.7 TWh is needed. This implies that an extensive extension of interconnection capacity would not bring much benefits for the Irish system. However, high-voltage alternating current (HVAC) lines could still bring the benefit of becoming integratred into the larger synchronous system, due to the synchronous penetration in GB. Given that the dominant technology is currently HVDC this is unlikely to happen in the near future.

Supported by INTELLIGENT ENERGY EUROPE

References

BROWN, A. 2009. Transmission Development Strategy for Northern Ireland.

CER. 2010. *Factsheet: Generator Connection Policy* [Online]. Commission for Energy Regulation. Available: http://www.cer.ie/en/information-centre-newsletters.aspx?article=67be448a-4401-4511-a679-9e64dfd05ce5 [Accessed 07.02. 2013].

CSO. 2013. *Population 1901-2011* [Online]. Irish Central Statistics Office Available: http://www.cso.ie/Quicktables/GetQuickTables.aspx?FileName=CNA13.asp&TableName=Population+1901+-+2011&StatisticalProduct=DB_CN [Accessed 12.01. 2013].

DCENR 2010. National Renewable Energy Action Plan - Ireland - Submitted under Article 4 of Directive 2009/28/EC. Department of Communications Energy and Natural Resources.

DCENR 2012. Strategy for Renewable Energy: 2012 - 2020. Department of Communication, Energy and Natural Resources.

DE DECKER, J. & KREUTZKAMP, P. 2011. Offshore Electricity Grid Infrastructure in Europe. *OffshoreGrid project.* A Techno-Economic Assessment Final Report, www.offshoregrid.eu.

DTTAS 2011. Irish Bulletin of Vehicle and Driver Statistics Department of Transport, Tourism and Sport www.dttas.ie.

EIRGRID 2008. Grid 25 - A strategy for the development of Ireland's electricity grid for a sustainable and competitive future.

EIRGRID 2009. Generation Adequacy Report 2010 - 2016.

EIRGRID 2011. North South 400kV Interconnection Development Preliminary Re-evaluation Report.

EIRGRID. 2012a. *About us* [Online]. Available: http://www.eirgrid.com/aboutus/ [Accessed 18.11. 2012].

EIRGRID. 2012b. *Eastwest interconnector* [Online]. Available: http://www.eirgrid.com/eastwest/news/ [Accessed 18.01. 2013].

EIRGRID, SEMO & SONI 2012. The DS3 Programme Delivering a Secure, Sustainable Electricity System (Brochure)

EIRGRID & SONI 2010. All-island Generation Capacity Statement 2011-2020.

EIRGRID & SONI 2011. All-Island Generation Capacity Statement 2012 - 2021.

EIRGRID & SONI 2012a. 2011 Curtailment Report

EIRGRID & SONI 2012b. All-Island Generation Capacity Statement 2013 - 2022.

EIRGRID & SONI. 2012c. *All-Island Transmission Map* [Online]. Available: http://www.eirgrid.com/media/All-Island%20Transmission%20Map.pdf [Accessed 06.02. 2012].

ENTSO-E. 2012. *Detailed Monthly Production (in GWh) for Ireland for Jan to Dec 2012* [Online]. Available: https://www.entsoe.eu/db-query/production/monthly-production-for-a-specific-country/ [Accessed 25.02. 2013].

ESB. *Turlough Hill* [Online]. Available: http://www.esb.ie/main/img/turlough-hill-1.jpg [Accessed 05.12. 2011].

FOLEY, A. M.; LEAHY, P. & MCKEOGH, E. J. 2009. *Wind Energy Integration and the Ireland-Wales Interconnector. Proceedings IEEE-PES/IAS Conference on Sustainable Alternative Energy*

FOLEY, A. M.; Ó GALLACHÓIR, B. P.; MILBORROW, D. J.; MCKEOGH, E. J. & LEAHY, P. G. Addressing the Technical and Market Challenges to High Wind Power Integration in Ireland, Renewable & Sustainable Energy Reviews, 2013, 19.

IWEA. 2012a. *About OffshoreWind* [Online]. Irish Wind Energy Association. Available: http://www.iwea.com/index.cfm/page/aboutoffshorewind [Accessed 12.12. 2012].

IWEA. 2012b. *County Wind Map* [Online]. Irish Wind Energy Association. Available: http://www.iwea.com/index.cfm/page/_windenergy_onshore [Accessed 12.12. 2012].

MC GARRIGLE, E. V., DEANE, J. P. & LEAHY, P. G. 2013. How much wind energy will be curtailed on the 2020 Irish power system? *Renewable Energy,* 55**,** 544-553.
MUTUAL*ENERGY*. 2009. *The Moyle Interconnector* [Online]. MutualEnergy A Northern Ireland company working for consumers. Available: http://www.mutual-energy.com/The_Moyle_Interconnector/Index.php [Accessed 18.12. 2012].
O'SULLIVAN, J. 2012. Delivering a Secure Sustainable Electricity System – a context. EirGrid and SONI.
ORGANIC POWER LTD 2011a. Energy Storage Hub Glinsk Mountain, County Mayo. *http://www.organicpower.ie/pdf/glinsk/OP18%20web%20brochure%20issue%203%20August%202011.pdf.*
ORGANIC POWER LTD 2011b. MAREX 2016 (Method for Atlantic Renewable Energy Export). *http://www.organicpower.ie/pdf/glinsk/MAREX%20Web%20Brochure%20Issue%201,%207%20September%202011.pdf.*
SCOTTISH GOVERNMENT, IRISH GOVERNMENT & NORTHERN IRELAND EXECUTIVE 2011. Irish-Scottish Links on Energy Study (ISLES), Executive Summary (Draft). www.islesproject.eu.
SEAI 2010a. Bioenergy Roadmap 2010 -2050. Sustainable Energy Authority Ireland
SEAI 2010b. Ocean Energy Roadmap 2010-2050. Sustainable Energy Authority Ireland.
SEAI 2010c. Residential Energy Roadmap 2010-2050. Sustainable Energy Authority Ireland.
SEAI 2011a. Electric Vehicles Roadmap 2011 - 2050. Sustainable Energy Authority of Ireland.
SEAI 2011b. Smartgrid Roadmap 2011 - 2050. Sustainable Energy Authority of Ireland.
SEAI 2011c. Wind Energy Roadmap 2011 - 2050. Sustainable Energy Authority of Ireland
SEMO. 2012. *About SEMO - The Single Electricity Market* [Online]. Single Electricity Market Operator. Available: http://www.sem-o.com/AboutSEMO/Pages/default.aspx [Accessed 18.11. 2012].
THE MAYO TODAY EDITOR. 2012. *4149-mayo-on-the-crest-of-a-green-energy-revolution* [Online]. Available: http://www.mayotoday.ie/index.php/browse-mayo-news-by-category/going-green/item/4149-mayo-on-the-crest-of-a-green-energy-revolution.html?tmpl=component&print=1 [Accessed 20.03. 2012].
WÄNN, A., REIDY, M., LEAHY, P., DOYLE, S., DALTON, H., BARRY, P. & MCKEOGH, E. 2012. Environmental Performance of Existing Energy Storage Facilities. *stoRE project - facilitating energy storage to allow high penetration of intermittent renewable energy.* Technical Report, www.store-project.eu.

Annex 1

Storage Operation in Scenario 2020 B and C

Figure 32 and Figure 33 shows the operation of the PHES system during the hours 1000 to 1336 for Scenario 2020 B and C respectively. Negative values demonstrate that the facility is in discharging mode and positive values show the PHES in charging mode. It can be seen that the PHES system is frequently charged and discharged completely and the is often used as well.

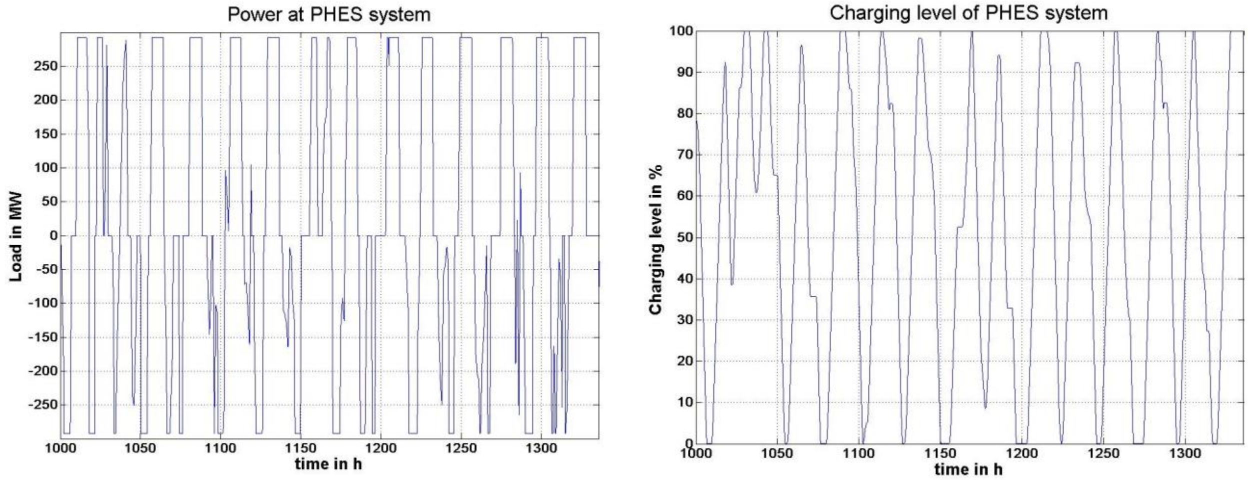


Figure 32: Two week zoom (hour 1000 to 1336) on PHES operation in scenario 2020 B

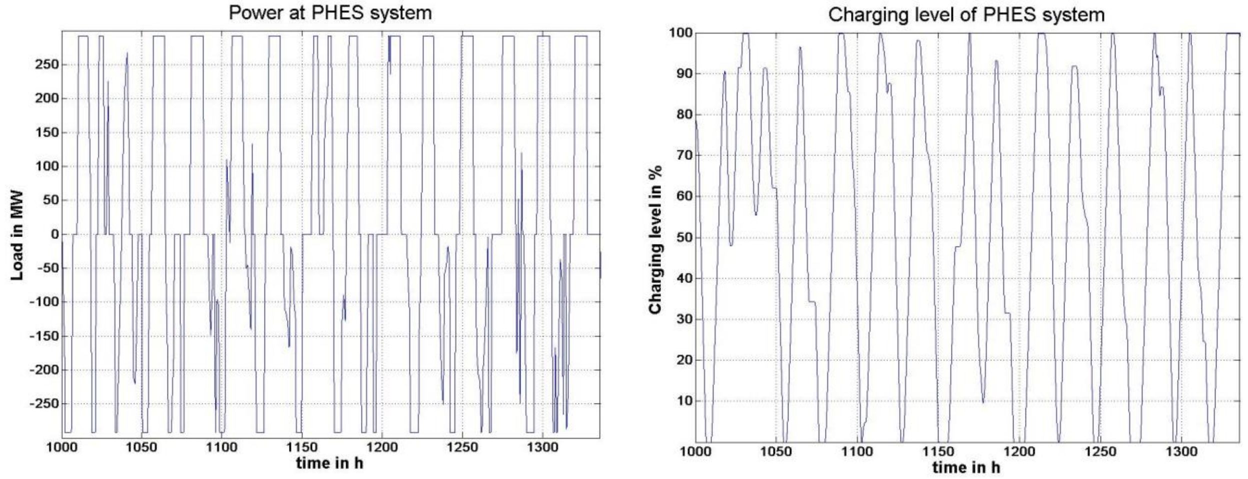


Figure 33: Two week zoom (hour 1000 to 1336) on PHES operation in scenario 2020 C

Supported by INTELLIGENT ENERGY EUROPE

Annex 2

Rejected Energy in Ireland 80 % Scenario and with transmission capacity 1 GW

Figure 34 illustrates the results of the investigations made for an interconnection capacity of 1 GW, Figure 35 illustrates the same for an unlimited interconnection capacity. The first image shows the rejected energy in Ireland without interconnectors, the second shows the rejected energy with interconnectors and the third shows the transmitted energy through these interconnectors. There is not much difference between the first two images; this is particularly clear towards the end of the year, when there is high feed-in from wind power. The same issue can also be observed in the image of transmitted energy. The interconnectors are not in use for large extents of time, especially from hour 7500 to the end of the year.

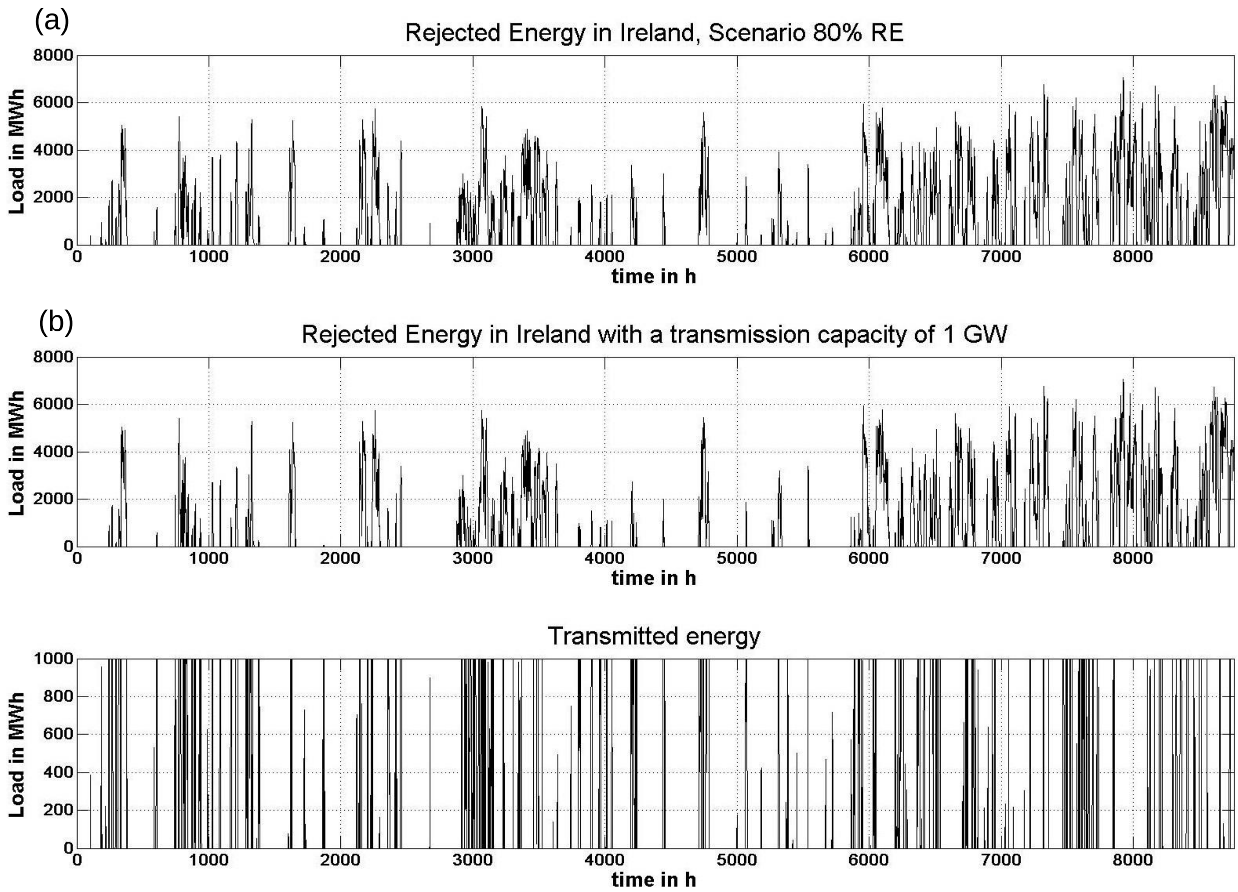


Figure 34: Rejected Energy levels in Ireland for the 80% scenario (a) and with transmission capacity of 1 GW (b) and the transmitted energy between ROI and GB.

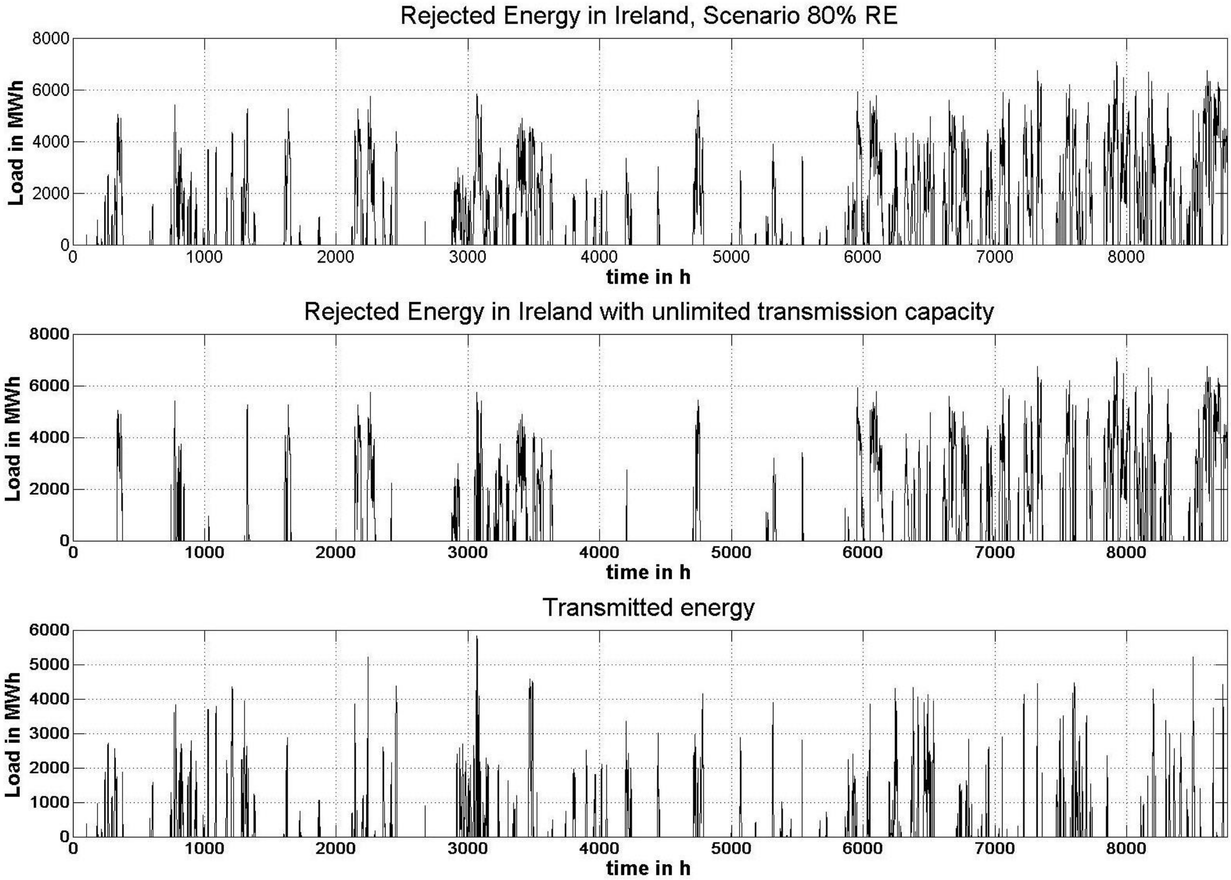


Figure 35: Rejected Energy levels in Ireland for the 80% scenario and with an unlimited transmission capacity and the transmitted energy between ROI and GB.