Facilitating energy storage
to allow high penetration of intermittent
Renewable Energies

stoRE
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Does Ireland need more storage?

Power system overview and RES integration

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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 Great Britain (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 currently planned for 2020, will only allow a small increase in wind power exports.

5. Additional energy storage capacity would be able to 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: a theoretical 70 GWh 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 environmental barriers, availability of suitable sites, costs and market conditions – factors which are addressed by the other workpackages in stoRE.

7. This study shows clear benefits from development of 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).

Workpackage 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 brochure provides an executive summary of the results from the full report "Future Energy Storage Needs in Ireland – Power System Overview and RES Integration". To view the full report please see http://www.store-project.eu/en_GB/project-results

The report 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 (gas turbines) and also one pumped hydro energy storage (PHES) facility.

The 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. New CCGT and peaking OCGT generators are planned for ROI during 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, linking 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 maximum capacity of 500 MW. Further planned interconnectors include an additional, internal North-South interconnector which will strengthen the grid system between NI and ROI. Other options for connecting future off-shore and near-shore development to the mainland in the ROI and Scotland have also been explored by the The Irish-Scottish Links on Energy Study.

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 some of the highest mean onshore wind speeds in Europe and offshore resources benefiting from Ireland's extensive 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 for ROI).

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

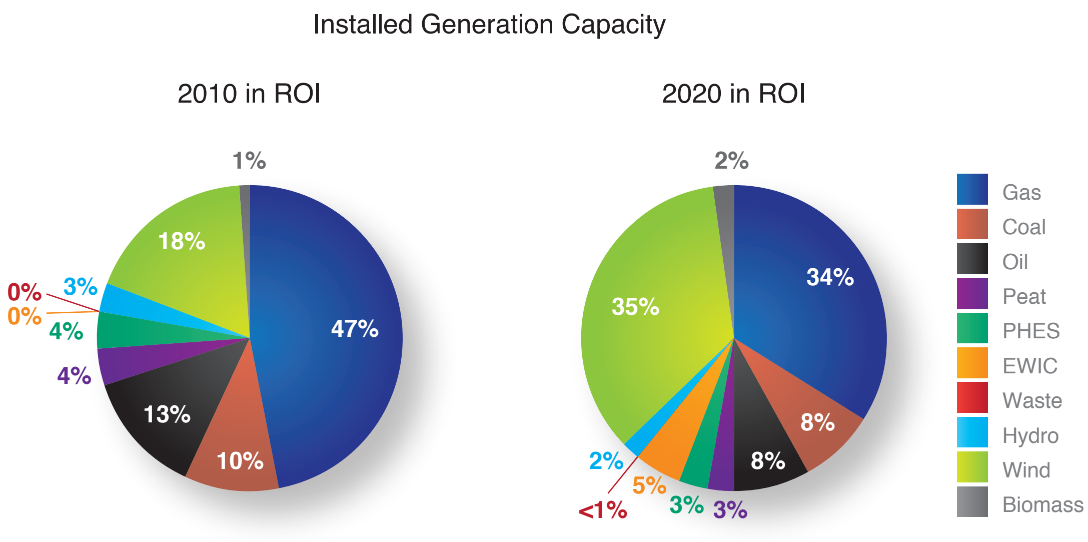


Figure 1:
Current (2010) and forecasted (2020) installed generation capacity for ROI. Source: (EirGrid and SONI, 2010, EirGrid and SONI, 2011, EirGrid and SONI, 2012b)

Energy Storage Development Plans

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

Already in 2011, EirGrid and Soni (2012a) reported wind curtailment levels of 2.2 %. Several studies have been made in regard 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 both the NREAP and the latest DCENR report on Strategy for Renewable Energy: 2012-2020 (2012) recognise that large scale storage facilities, specifically PHES and CAES, merit attention, no overall plan exists yet for such infrastructure. 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.

3

Reference and Future Development Scenarios

A reference scenario and two future 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 a 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

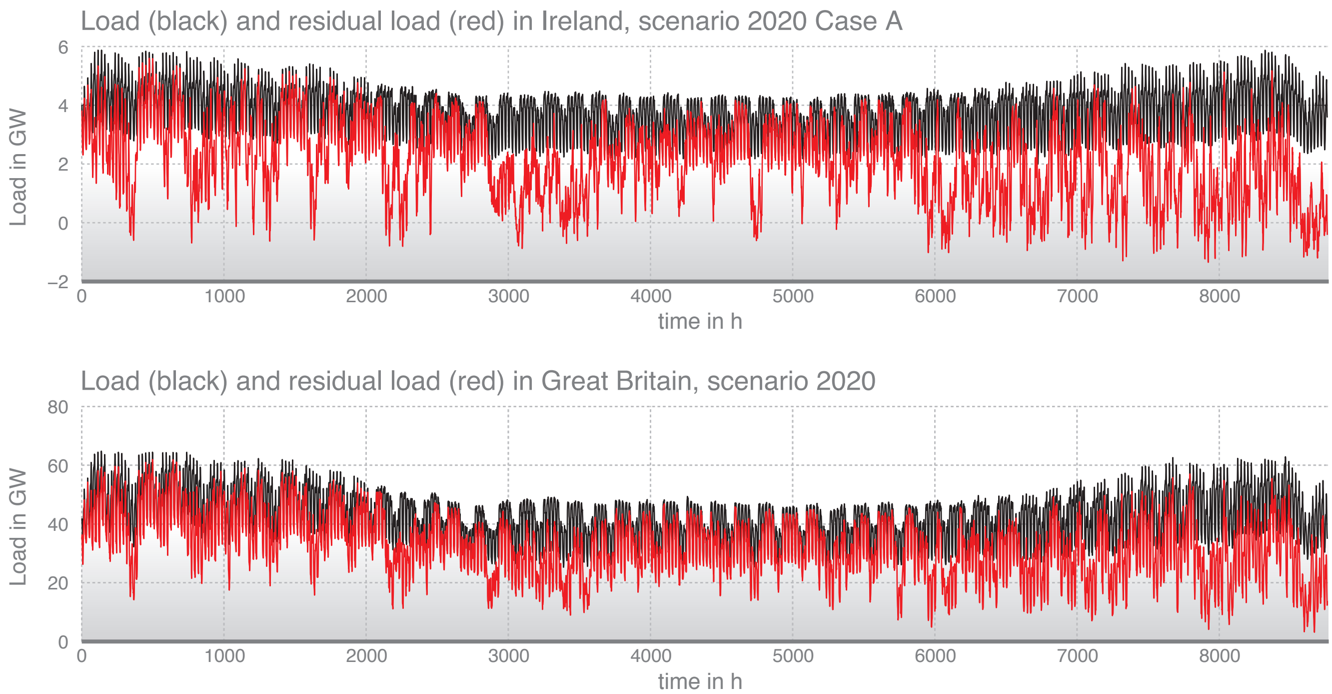
The residual load (RL) is defined as the load demand minus non-controllable generation from variable renewables, such as wind power and the non-controllable portion of hydropower. Bioenergy generation is regarded as controllable. A negative RL indicates that there is a surplus of fluctuating renewable 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 (33.6 % RES) and Case C (42.8 % 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.

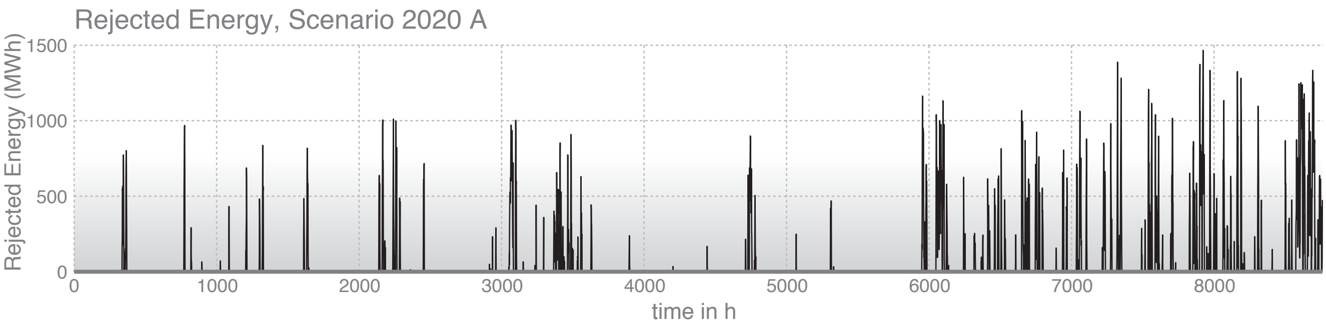
By 2020 the RL in ROI is negative for some of the time (Figure 2 shows scenario 2020 Case A), which indicates a surplus of fluctuating renewable electricity that can be exported, stored or else needs to be curtailed. Also shown in Figure 2 is the RL for Great Britain in 2020. The pattern of GB and ROI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

Figure 2:
Load demand (black) and residual load (red) in Ireland 2020 Case A (above) and Great Britain (below)



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

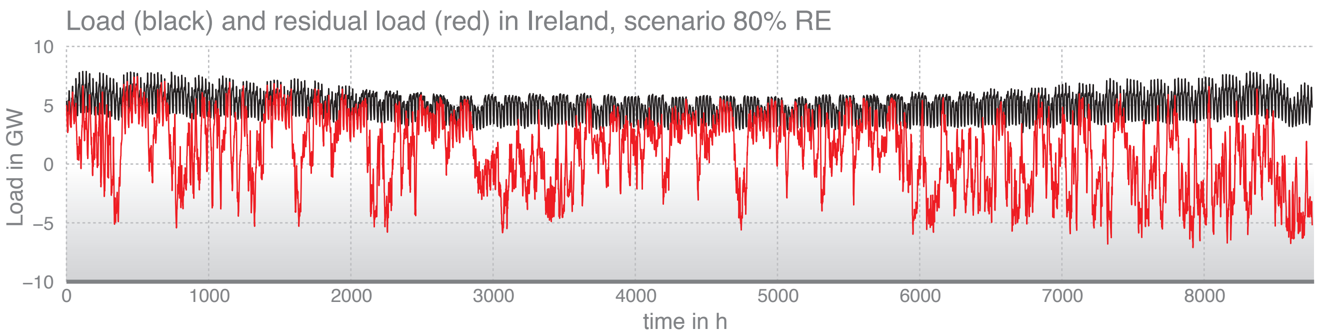
Figure 3:
Hourly rejected energy in the 2020 Scenario, Case A for the full year

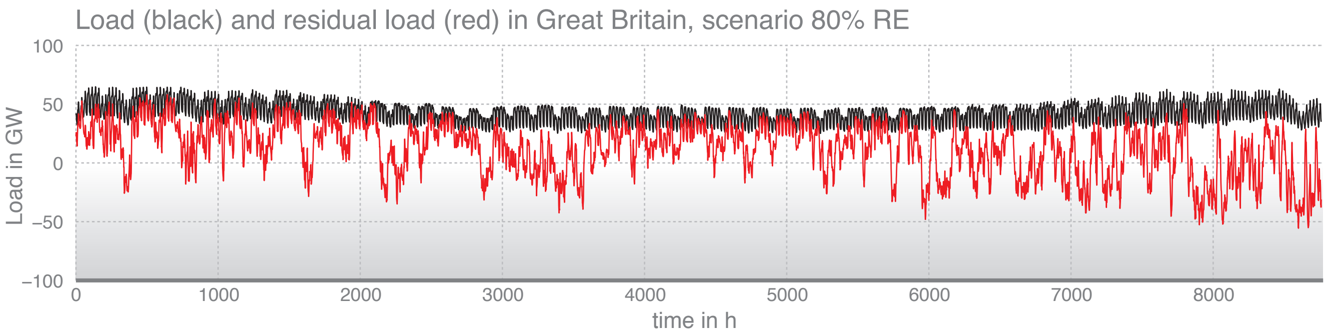


b. Cases Examined within the 80 % Renewable Energy Scenario

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 different interconnector capacities (1GW, 2 GW, unlimited). For this reason, a simplified British system was also modelled. 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, especially in regards to load demand.

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.

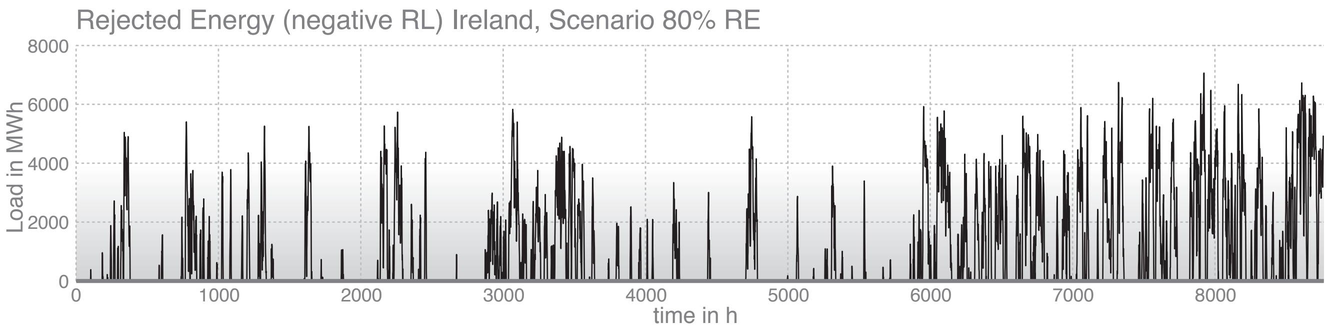


Figure 5:
Hourly rejected energy in the 80 % RE Scenario for the full year

Variations in Load and Residual Load

The load variation was also calculated for the 2020 Scenarios in GW over intervals of 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, with the of variations being much greater in magnitude than variations in the load itself. 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. For Ireland no expansion of the ESS is expected, which means that only Turlough Hill with its 292 MW has been taken into account for the first energy storage esystem. 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

In the unlimited storage capacity simulation, zero wind energy will be rejected. The need for energy storage capacity as determined by system 2 is fairly similar in 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

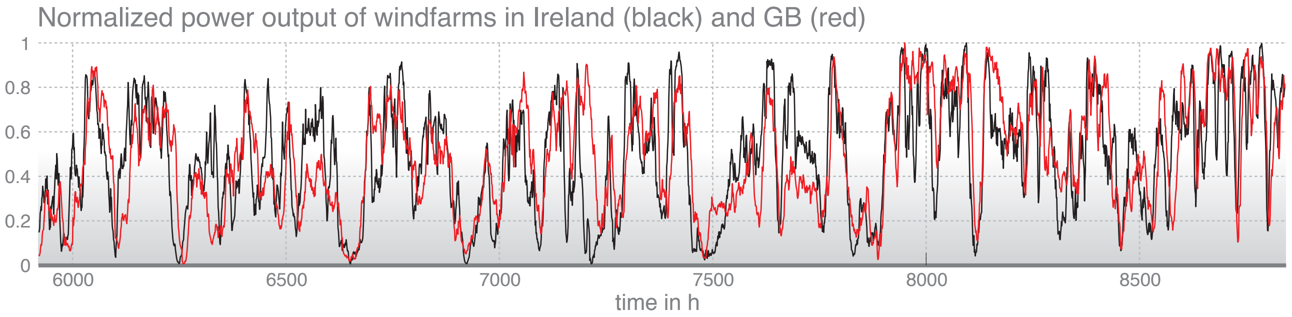
In this scenario one of the notable differences as compared to the 2020 scenario is that the residual load is negative for long periods of time. This means that the storage units are also used less than in the 2020 scenario, because they reach their limit more frequently and have to wait for the residual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

The simulation data is based on a particular wind year, 2011, which has a very high feed-in from wind in the latter half of the year. This results in a 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.

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 also a surplus in the British grid (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 a widespread expansion of interconnection capacity would be of little benefit to the Irish system.

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

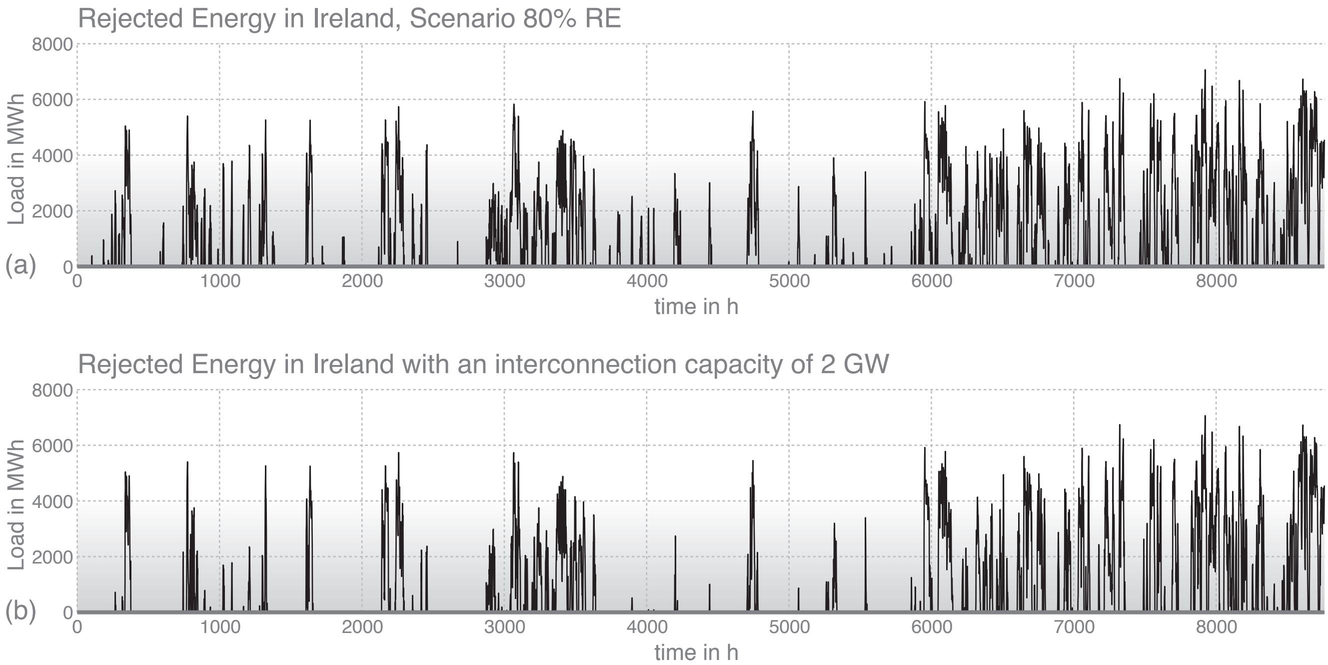


Table 3: Needed Storage Capacity under different Cases for Scenario 2020 and 80% when no wind power is curtailed

	Unlimited Energy Storage System		
	Needed Power (GW)		Needed capacity (GWh)
	Charging	Discharging	
A (2020)	1.83	1.79	59.12
B (2020)	1.73	1.60	14.32
C (2020)	1.86	1.76	70
80 %	6.8	4.3	2700

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/energy storage 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 are similar to those of the 2020 scenario, with the need for storage capacity reaching 2.7 TWh in the 80% RE scenario.

The results show the required energy storage capacity for zero wind curtailment. This exercise is undertaken for illustrative purposes as it should be noted that 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 similar levels of 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 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 of approximately 2.7 TWh is needed in order to reduce rejected RES-E to zero. This implies that a significant 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.

Further Reading

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List of Abbreviations

CAES	Compressed air energy storage
CCGT	Combined cycle gas turbine
DCENR	Department of Communications, Energy and Natural Resources
ESS	Energy storage system
EST	Energy storage technologies
EWIC	East-West Interconnector
GB	Great Britain
GW	Gigawatt
GWh	Gigawatt hour
HSU	Helmut Schmidt University
MW	Megawatt
MWh	Megawatt hour
NI	Northern Ireland
NREAP	National Renewable Energy Action Plan
OCGT	Open cycle gas turbine
PHES	Pumped hydro energy storage
PV	Photovoltaic
RE	Renewable energy
RES	Renewable energy sources
RES-e	Renewable electricity sources
RL	Residual load
ROI	Republic of Ireland
SEAI	Sustainable Energy Authority Ireland
SONI	System operator for Northern Ireland
TSO	Transmission system operators
TWh	Terawatt hour
UCC	University College Cork

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 above and more information about them and the project is available on www.store-project.eu