COSTS AND BENEFITS OF GB INTERCONNECTION

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A Pöyry report to the National Infrastructure Commission

February 2016

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EXECUTIVE SUMMARY

Introduction and approach

Over the last few years, commercial interest in GB interconnection projects has noticeably increased with ~10GW of new interconnection capacity proposed by 2025. The growing project pipeline can be seen as a natural commercial response to the changing market and regulatory environment. However, the impact on the operation of the GB energy system of such a fundamental shift in interconnector capacity is still uncertain, as is the ability to realise projected benefits for the developers, consumers and the wider economy as interconnection capacity with particular countries or regions grows.

As part of the National Infrastructure Commission's (NIC's) investigation into key national infrastructure challenges, the NIC has asked Pöyry to review the costs and benefits of interconnection, drawing on the existing evidence base. The aim of this report is to highlight to what degree the conclusions from pre-existing work are robust to the high degree of uncertainty about the future of European electricity markets.

Pöyry has drawn upon a range of reports, studies and other publications to form the evidence base for this report. These documents have been reviewed to compile common conclusions on the socio-economic welfare impacts and wider societal costs and benefits of interconnectors serving GB.

Benefits of interconnectors

There is strong agreement that the socio-economic welfare value of interconnectors comes from their ability to improve the efficiency of outcomes in the electricity system, lowering the cost of meeting demand and of achieving other policy objectives such as improving security of supply and enabling more efficient renewables integration.

The overwhelming majority of literature reviewed concluded that additional interconnection beyond current levels is likely to bring significant benefits to the UK. However, whether particular interconnector combinations provide a net benefit to GB and the wider system depends on several aspects:

- the boundary conditions, i.e. which stakeholders are included in the analysis, in which countries and what categories of costs and benefits are included;
- the objective function, e.g. welfare maximisation, cost minimisation, carbon minimisation; and
- the specific market modelling assumptions, e.g. commodity prices, capacity build and future energy policy assumptions.

Therefore comparability between conclusions of studies is hard as while they often look at the same impacts they do it through a different lens. It is important to acknowledge that the majority of studies look at societal benefit, not the incentives on a commercial developer.

Sources of socio-economic welfare value

The socio-economic welfare value of interconnectors comes principally from balancing the capital and operational costs of new connections with cost and efficiency improvements represented by hourly wholesale price differences between markets. Such wholesale price variations between markets provide the key market signals for interconnection and by exploiting these differences interconnectors affect the socio-economic welfare of the system. This wholesale price value can be helpfully differentiated into three main types:

- **wholesale price level value**, where prices differ on an annual average basis i.e. largely intrinsic value as can be traded ahead of time, with future value driven by commodity prices;
- **wholesale price shape value**, where prices differ in their underlying average shape over a period in a way that can be predicted i.e. a mix of intrinsic (i.e. average price differential) and extrinsic value (i.e. hourly price differentials, tradable only very close to real-time due to forward market granularity issues), robust over relatively long-time periods; and
- **wholesale price volatility value**, deriving from unpredictable price peaks and troughs which only appear close to real-time i.e. largely extrinsic value, dependent chiefly on difficult to forecast events and the roll-out of intermittent generation.

In addition, value for certain interconnectors can come from their ability to provide **services to System Operators** (i.e. balancing and ancillary services) and provide **capacity contribution** in one or both markets they connect, represented in GB (and some other European markets) by payments under a capacity market.

The importance of each value source will vary between markets and will also change over time (depending on renewables and storage deployment, electrification of heat and transport, smart grid development, etc.). There are likely to be more persistent arbitrage opportunities with some markets than others (e.g. Norwegian interconnector arbitrage opportunities are high in most scenarios presented in the studies reviewed). The review suggests a general agreement that the importance of extrinsic value is likely to increase in the future.

Security of supply

Interconnectors can potentially increase the security of supply in one or more electricity systems. However, additional interconnector capacity could displace domestic sources of generation. The net of these effects is uncertain and the impact on both systems will be dependent on the detailed assumptions of a study.

Some of the criticism of interconnectors has been directed at the lack of economic rationality in flows. While this has been an issue in the past, it is less prevalent now with improved market coupling at the day-ahead stage and the structures being introduced under the target model.

The extent to which interconnectors displace capacity in GB depends on how they are treated in the capacity market, especially with regard to de-rating factors and the assessment of required capacity that is procured through the auctions. If de-rating factors are applied appropriately, interconnectors should not be inferior to generation capacity in the capacity mechanism. However, given that these de-rating factors are based on projected price differentials, some uncertainty and risk remains as these projections could be incorrect. This risk is mitigated by:

- using conservative de-rating factors; and
- re-assessing the contribution of interconnectors every year and determining the factors only four years in advance to capture changing market dynamics.

The potential for interconnection to have a complex impact on security of supply highlights some need for harmonisation and coordination between TSOs and Market Designs, which is being promoted by European authorities such as the European Commission and ACER.

Environmental effects

At an EU level, interconnection is seen as a necessary means of achieving a lower cost decarbonisation pathway. Increased interconnection may lead to offsetting impacts on national renewables targets, it may reduce curtailment, making support more efficient and avoiding additional capacity build. If wholesale prices fall due to interconnector flows, this may increase the need for renewable support payments, though the effect on consumers may not be any different.

Some of these benefits could be captured in wholesale prices, thereby providing a market signal for interconnection and allowing for clear inclusion in a CBA. However major policy inefficiencies persist such as differences in carbon costs between countries and a lack of harmonisation of renewable policy support between EU member states. This creates a risk of inefficient flows on the interconnector as well as the potential for over/under-investment in a level of interconnection consistent with a lowest cost EU wide decarbonisation pathway.

Future levels of interconnection

Since interconnectors change prices, decreasing marginal returns from additional interconnection and stronger impacts on other existing interconnectors in the long-term are expected as price arbitrage opportunities and revenues may be cannibalised.

There is strong evidence to suggest that additional capacity close to that currently agreed (ranging between 9GW and 11GW across different studies) will provide a net benefit to GB under many circumstances[1]. However, it is less clear whether significant additional interconnection beyond that will produce benefits to GB. The value of this interconnection will very much be asset and market specific and require more detailed consideration. Analysis focusing on GB suggests falling marginal benefits of certain additional interconnector capacity in at least in some market scenarios but more analysis would be beneficial. The majority of EU-wide studies would support much higher levels of interconnection, as these assess benefits over a wider geographical area.

Where interconnectors offer benefit to the wider European system rather than specifically to GB, this benefit could be shared appropriately so that GB can be a net beneficiary. Mechanisms for such transfers are considered further in ACER’s proposed cross border cost allocation (CBCA) methodology.

Policy and regulatory barriers

From a commercial perspective, the increasing importance of less bankable arbitrage opportunities (especially volatility) could create a potential barrier for investment in interconnection, as a large infrastructure asset. This, together with current European regulation (allowing the European Commission to impose a cap on revenues for

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[1] Although we note that evidence reviewed is not universally in favour, highlighting the need to carefully consider objective functions and market assumptions when drawing conclusions.

merchant interconnector projects) could make interconnectors high-risk projects with limited upside.

To address these issues, Ofgem has created the cap and floor regime, providing a level of downside security in exchange for giving up some upside potential. The strong uptake from cap and floor window 1 and the pipeline of additional proposed projects can be seen as, at least in part, representative of the removal of that barrier. There is no particular evidence from the review that additional material policy/regulatory barriers are restricting the ability of otherwise beneficial interconnectors from coming forward.

Competing Flexibility Options

Increasing intermittent generation resources and changing demand patterns will lead to greater and more complex needs for flexibility in wholesale electricity markets, due to increased forecast errors. Currently, most of that flexibility is provided by back-up generation, and, to a lesser extent, demand side response and interconnectors.

The literature reviewed agrees that interconnectors are capable of providing a range of flexibility to the GB system both directly through the transfer of energy but also indirectly by enabling access to other sources of flexible generation. While there will be some competition with interconnectors and other sources of flexibility, it appears likely that there will be room for a significant range of new entry because of:

- the different scale of the various technologies and their focus on different sources of value; and
- the scale of the increase of flexibility requirements.

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1. INTRODUCTION

1.1 Context

In 2011 and 2012, the first new GB electricity interconnectors in over a decade were commissioned, creating an additional link to the Irish Single Electricity Market (SEM) and establishing the first direct link with the Netherlands. These projects, while representing around a 60% increase in GB interconnection capacity, still left GB well adrift of the European Commission's target, as part of delivering the internal market, to achieve interconnection of at least 10% of domestic installed generation capacity[2]. In 2015 GB interconnection capacity (see Table 1) was less than half way to this target, standing at 4.4%[3].

Table 1 – Existing interconnectors serving GB

Name	Developers	Connected market	Capacity	Commissioning date
IFA	NGIH and RTE	France	2,000MW	1986
Moyle	Mutual Energy	Irish SEM	500MW	2002
BritNed	NGIH and TenneT	Netherlands	1,000MW	2011
EWIC	EirGrid	Irish SEM	500MW	2012

However, over the last few years, commercial interest in interconnection projects to GB has noticeably increased. A list of known projects under consideration is presented in Table 2 and Figure 1. This includes all projects that are reported in the European Commission's Project of Common Interest (PCI) list. If all these projects were developed it would amount to almost 10GW of new interconnection by 2025 (or around 10% of domestic installed capacity) and would increase the number of markets with which GB is directly connected from three to seven. This increased interest in interconnection is not restricted to GB, with ENTSO-E's Ten Year Network Development Plan (TYNDP) 2014 calling for a doubling of European interconnector capacity by 2030[4].

2 First introduced in the "Presidency Conclusions - Barcelona European Council" in March 2002 **[REF1]**

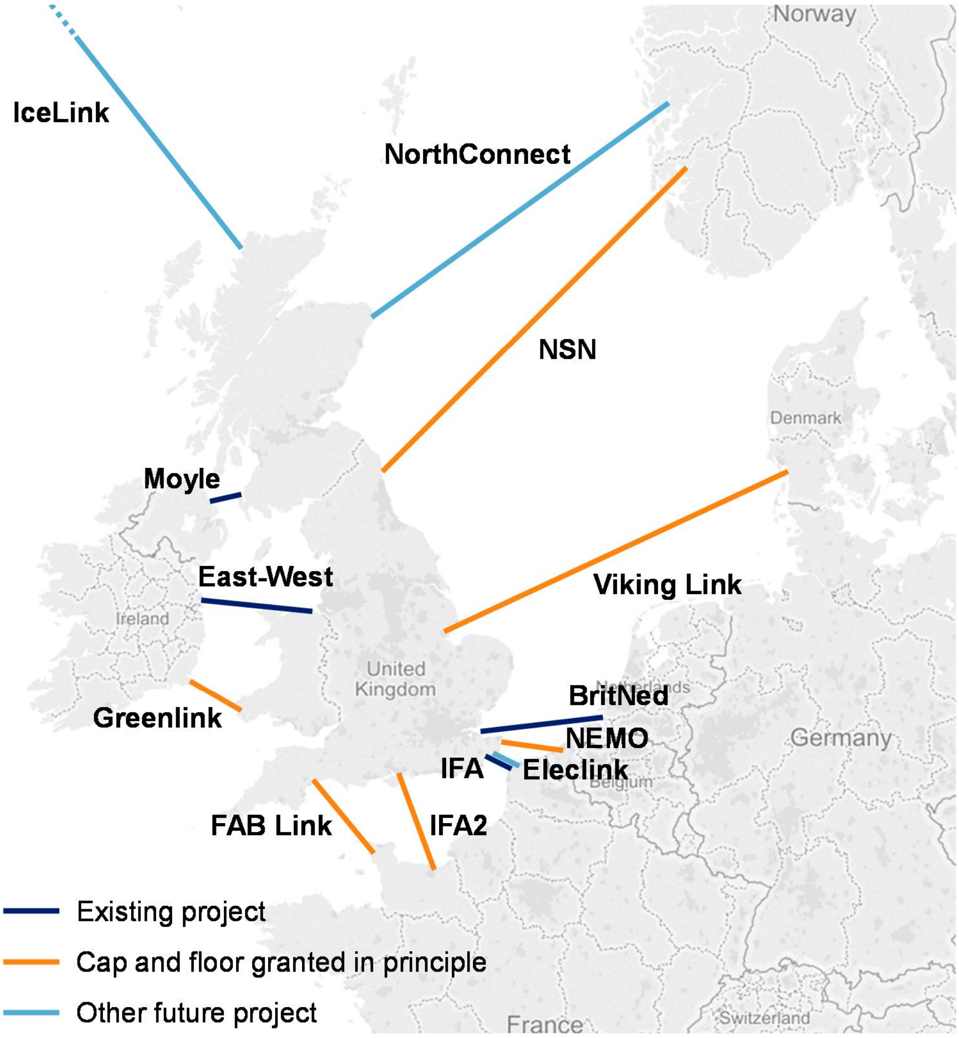
3 In 2015, domestic installed capacity in GB was 91.0GW, while interconnection was 4.0GW. This does not take account of the fact that the Moyle interconnector to Northern Ireland is currently operating at half its capacity.

4 '10-Year Network Development Plan 2014', ENTSO-E, October 2014 **[REF2]**

Table 2 – Proposed GB interconnectors

Name	Developers	Connected market	Capacity	Suggested commissioning date	Status
NEMO	NGIH and Elia	Belgium	1,000MW	2019	Cap and floor granted; preparation for construction
Eleclink	Star Capital and Groupe Eurotunnel	France	1,000MW	2019	Exemption granted; offering capacity
IFA2	NGIH and RTE	France	1,000MW	2020	Cap and floor granted; consultations
NSN	NGIH and Statnett	Norway	1,400MW	2021	Cap and floor granted; construction
Greenlink	Element Power	Irish SEM	500MW	2021	Cap and floor granted
FAB Link	Transmission Investment and RTE	France	1,400MW	2020-2022	Cap and floor granted; detailed surveys
Viking Link	NGIH and Energinet.dk	Denmark	1,000MW	2022	Cap and floor granted; surveys
North Connect	Agder Energi, E-CO, Lyse and Vattenfall	Norway	1,400MW	2022	Development studies
Ice Link	NGIH and Landsvirkjun	Iceland	800-1,200MW	2024	Development studies

Figure 1 – Map of existing and proposed GB interconnectors



1.2 Scope of this report

The growing project pipeline can be seen as a natural commercial response to the changing market and regulatory environment. Arbitrage opportunities between GB and other markets are increasing due to both market factors, such as more volatile markets created by increased deployment of intermittent renewable generation, and policy factors, such as the carbon price difference between GB and other European markets created by the UK carbon price support (UK CPS).

However, the impact on the operation of the GB energy system of such a fundamental shift in interconnector capacity is still uncertain, as is the ability to realise projected benefits for the developers, consumers and the wider economy as interconnection capacity with particular countries or regions grows.

In its role of reviewing the long-term infrastructure needs in GB and providing impartial advice to ministers and Parliament, the National Infrastructure Commission (NIC) launched a Call for Evidence on 13 November 2015 on three key national infrastructure challenges. One of these challenges is improving how electricity demand and supply are balanced with particular attention to **the roles of storage and interconnection as a means of reducing the costs of the electricity system**.

As part of this investigation, the NIC has asked Pöyry to **examine the costs and benefits of interconnection, drawing on the existing evidence base**. The aim of this report is to highlight to what degree the conclusions from pre-existing work are robust to the high degree uncertainty about the future in European electricity markets.

Pöyry has drawn upon a range of reports, studies and other publications to form the evidence base for this report. These documents have been reviewed to compile common conclusions on the costs and benefits of interconnectors serving GB.

This report focuses on the socio-economic welfare and wider societal benefits of electrical interconnectors connecting GB to other European markets. This includes all market-to-market interconnector projects, fully merchant or cap and floor regulated. We exclude offshore grid projects from this study, i.e. combined networks including generation and bootstraps to existing onshore grids (such as the ISLES project).

Based on the above, the key questions identified for this report were:

- **What are the impacts that interconnection has on GB and what drives these impacts?**
- **Why would interconnection be beneficial to GB stakeholders?**
- **What level of additional interconnection to which markets could be beneficial to GB stakeholders?**
- **Are there ways to integrate interconnectors without foreclosing the market for other technologies providing flexibility?**

Sources

The evidence base for this report is comprised of government and regulatory publications from both European and national authorities (European Commission, DECC, Ofgem), independent studies, TSO publications, academic papers, and consultation responses.

A full list of references can be found in Annex A. The principal references in this report are numbered in Annex A.1 and referred to by this number in the footnotes (in the form **[REF#]**).

1.3 Structure of this report

This report is structured as follows:

- Section 2 introduces the areas of impacts of interconnectors;
- Section 3 outlines the cost and efficiency impacts identified for interconnectors;
- Section 4 examines other interconnector impacts, such as security of supply (4.1), environmental and social impacts (4.2);
- Section 5 looks into two topics of particular interest in relation to interconnectors serving the GB market: interactions between interconnectors (5.1) and interconnectors as a source of flexibility (5.2);
- Section 6 summarises the key findings and insights from the analysis presented in previous sections; and
- Annex A provides references to the documents reviewed as evidence base for this study.

2. AREAS OF IMPACT OF INTERCONNECTION

2.1 Overview of interconnection impacts

The existing literature identifies a range of impacts that interconnectors can have on the operation of the electricity market, the robustness and cost of the electricity system and the achievement of energy policy objectives in GB. Though studies and analyses differ in their core objectives and scope, there appears to be a broad consensus on the nature of the impacts they assess. These impacts map closely to the components of cost-benefit or impact assessments and can be categorised into three main groups:

- impacts on cost and efficiency of the electricity system;
- impacts on security of supply and electricity networks[5]; and
- environmental and social effects.

Additionally, there are a number of hard-to-quantify or hard-to-monetise benefits, such as impact on market liquidity, that are mentioned in a subset of interconnector studies.

Table 3 summarises the specific elements that are generally covered under each of the main areas. Our observation is that the impacts on cost and efficiency are widely quantifiable and have formed the basis of much of the assessment of the current and future impacts of interconnectors. Thus, these are presented in detail in Section 3. The other areas appear to be covered in less detail and are examined in Section 4 of this report.

It is worth noting that these impact elements are not necessarily mutually exclusive, especially between types of impacts. For example, while CO_2 emissions are picked up to an extent in the cost and efficiency metrics, reducing domestic CO_2 emissions could be a goal in itself and therefore be analysed separately as an environmental metric.

5 Interestingly in continental Europe, the assessment of cross-border interconnection are traditionally much more closely aligned with other forms of transmission asset – in such cases costs are recovered from network users and the benefit is assumed to come from maintaining an agreed security of supply.

Table 3 – Impacts of interconnectors

Type of impact	Impact element
Cost and efficiency	Consumer bills
	Efficiency of dispatch over wholesale energy market and balancing time frames
	Efficiency of investment in both Generation and Transmission
	Efficiency in the provision of ancillary services (including constraint alleviation)
	Price volatility
	Intra-day integration
	Integration of renewable energy sources
	Profitability of electricity generation
	Transmission losses
Security of supply	Loss of load expectation
	Expected energy unserved
Environmental and social	Decarbonisation, CO_2 emissions and accessing renewable resource
	Local infrastructure and jobs
	Tax revenues
	Other environmental
	Connected industries
Other and hard to quantify	Market power and competition
	Market liquidity
	Market design

2.2 Importance of study parameters on conclusions on interconnector costs and benefits

The range of impacts of interconnectors identified in the literature highlights a key issue for this review - whether particular interconnector combinations provide a net benefit to GB and the wider system will depend on the study parameters. The key differentiators between studies are:

- the questions being asked (i.e. where quantified, the objective function), e.g. welfare maximising, cost optimisation, carbon minimisation, etc.;
- the boundary conditions, i.e. which stakeholders are included in the analysis, in which countries and what categories of costs and benefits are included; and
- the specific modelling assumptions on:
  - market conditions, e.g. commodity prices, future energy policy and capacity build assumptions; and
  - the 'counterfactual' against which the proposed interconnectors are assessed – i.e. what is assumed to happen in the absence of the interconnector (ENTSO-E

guidelines imply just amending IC as a starting point but other studies take a variety of approaches – choosing alternative investments or clustering projects can drive different results)[6].

Comparability between conclusions of studies is therefore hard as while they often look at the same type of impacts they do it through a different lens. As there is no one ‘correct’[7] approach such different results are therefore to be expected.

However, a key finding of the work is that the overwhelming majority of literature reviewed concluded that additional interconnection beyond current levels is likely to bring significant societal benefits to the UK. Where the results differ, they tend to do so as the studies:

- consider levels of interconnection beyond those currently proposed;
- assume very different market conditions to those today (such as a very large expansion of RES); and/or
- assume different boundary conditions such as optimising whole EU system costs or assuming that inefficiencies in policy are borne by interconnectors and continue for the full life of the project.

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6 ‘ENTSO-E Guideline for Cost Benefit Analysis of grid Development Projects’, ENTSO-E, February 2015 **[REF3]**

7 However, it seems logical that, in order to incentivise investments that are likely to provide fundamental net benefit under a broad socio-economic case in the long-run, interconnectors should be assessed in a range of market conditions and robust to future policy decisions.

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3. INTERCONNECTOR IMPACTS ON COST AND EFFICIENCY OF ELECTRICITY SYSTEMS

3.1 Types of interconnector arbitrage value

3.1.1 Wholesale electricity price arbitrage

The primary value of interconnectors derives from their ability to exploit price arbitrage opportunities between markets over various wholesale market timescales (i.e. forward markets, hourly day-ahead and within-day markets). Three main types of arbitrage value exist for interconnectors:

- **Price shape value**: Shape value is created by a different pattern of prices over a period. These patterns are often a consequence of established and persistent differences in demand profiles. For example, across continental Europe demand begins to ramp up before 6 a.m. whereas in GB this ramp up occurs after 6 a.m. Accounting also for the time difference, this creates a potential shape value even if there is no average price level differential or volatility. While price shape value is more predictable and certain than price level value, factors such as electrification of heat and transport and disruptive technologies such as storage and smart network solutions still lead to changes in value in the medium- to long-term.
- **Price level value**: This arises from differentials in average baseload prices, caused by differences in generation mix, fuel and carbon prices, transmission and balancing charges, and taxes. This is significant in certain markets – for example, between GB and Norway, where one country has a predominantly fossil-fuel based generation mix and the other a hydro-based system – but may vary with changes in weather patterns, fuel prices, carbon prices or installed capacity base.
- **Volatility value**: Unpredictable price peaks and troughs related to plant outages, demand spikes, weather patterns, etc. can also create differentials between markets much closer to real-time. Where interconnector flows can respond to these changes they can provide large value. However, by its nature, this value is very uncertain.

Enabling markets to respond to these various price differentials can improve the short-run efficiency of dispatch. Generation that would have been out of merit in the lower-priced market may still be able to be dispatched in the interconnected market in place of more expensive generation, reducing the overall dispatch costs in the system.

However, it is important to recognise that if there are distortions in price signals between markets (such that prices do not reflect costs) interconnector flows could lead to suboptimal solutions. This can be due to differences in carbon prices or transmission charges making operation of less efficient plant in continental Europe or Ireland cheaper than more efficient plant in GB.

In Aurora's scenario[8], such inefficiencies lead to an increase in overall European CO_2 emissions, in contrast to the general perception elsewhere in the literature that interconnection decreases these emissions.

8 'Dash for Interconnection', Aurora Energy Research, February 2016 **[REF4]**

3.1.2 System operation or balancing market services

Similarly, in operational timescales, it is also possible for interconnectors to contribute to ancillary services and balancing markets, potentially providing services cross-border and reducing the total cost for their provision. In GB, National Grid has acknowledged that interconnectors could be potential providers of a range of ancillary services, such as frequency response, black start and reactive power reserve[9].

Furthermore, as renewable generation increases, interconnectors may provide the flexibility to export excess electricity and in extreme cases, alleviate the need to curtail intermittent generators. At the same time, interconnectors can provide flexible response to unexpectedly low output of intermittent resources.

This can be a benefit to GB if interconnectors can provide flexibility services more efficiently than other sources. While there appears to be a broad consensus that the requirement for flexible electricity sources will grow in the future, there is a great degree of uncertainty around the sources of that flexibility. The arguments for interconnectors and other sources of flexibility are discussed separately in Section 5.2.

It is still unclear how readily interconnectors will be able to access cross-border ancillary services markets. Annex 5 of ENTSO-E's CBA guidelines highlights that in order to be able to provide reserve-type services, interconnectors would need to withhold capacity in the electricity markets, which may or may not be desirable or allowed. Further analysis is required regarding the impact this could have on future incentives for interconnector development.

3.1.3 Investment cost in transmission or generation capacity

In the longer term, interconnectors can affect investment decisions in both new power stations and the transmission network as they offer an alternative means of meeting our electricity needs through building additional capacity to import the required generation capability. While this may in some cases require additional network reinforcement onshore, it can offset reinforcement needs in others with the overall effect of lowering the cost of meeting electricity demand.

In Redpoint's 2013 study for Ofgem, the impact of additional interconnectors on costs for removing boundary constraints was investigated. The analysis shows that a combination of interconnectors with a capacity of 10.5GW could provide annual savings in transmission boundary reinforcements of £45.6m (real 2012 money) for the B6 boundary between southern Scotland and northern England. For the B14 boundary (enclosing London), a different combination of interconnectors could provide benefits of £7.6m per annum.

The benefit of avoided investment in generation capacity is investigated less often, as interconnector assessment studies tend to examine the impact of a project on a static system, in order to highlight the impact of the interconnector in isolation. In 2013, EirGrid and National Grid conducted a study on an additional GB-Ireland link (500MW)[10]. Of the £60m per annum benefit between the two jurisdictions found in that study, 40% were attributed to generation capacity savings.

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9 'Benefits of Interconnectors to GB Transmission System', December 2014 **[REF5]**

10 'Connecting Wind Generation in Ireland to the Transmission Systems of Great Britain and Ireland', EirGrid and National Grid, February 2013 **[REF6]**

Depending on how the analysis is conducted, investment in interconnection can also be seen to off-set the need for investment in generation capacity. Aurora estimates that by adding £2bn in interconnection between 2016 and 2035, the need for investment in CCGT and peaking capacity in GB would be reduced by £1.5bn (from £7.7bn to £6.2bn)[11].

Savings in transmission capacity would affect both producer and consumer welfare, as both generators and demand would face lower transmission charges (and vice-versa – higher costs would lead to higher charges). In the case of generation capacity, generators would be affected directly by savings in investment costs, while consumers would be affected indirectly (and possibly not at all) by the interconnector's effects on the capacity market.

3.2 Distribution of costs and benefits among stakeholders

3.2.1 Pure wholesale price effects

Since interconnectors derive their value from price differentials between two markets, the realisation of the overall benefit within a system will still create winners and losers. Interconnectors derive welfare whenever prices are sufficiently far apart for the interconnector to capture congestion rent. In simple terms, the direction of flow on the interconnector determines the other winners and losers from a socio-economic perspective[12]:

- Consumers in GB benefit from an interconnector importing, and thus accessing cheaper sources of generation. When interconnectors are exporting, additional domestic supply is required to meet demand, leading to wholesale price increases, and therefore a negative impact on consumers.
- GB producers benefit from exports on interconnectors, as they lead to additional generation required and a higher captured wholesale price. On imports, GB generators are displaced in the merit order and face lower captured prices, leading to lower gross margins.

Because of the potential magnitude of these distributional effects, interconnectors tend to divide opinion between stakeholders.

The issue of distribution of costs and benefits across stakeholder groups is tied up with the study parameter discussion in Section 2.2. A given assessment will naturally draw a boundary on both which types of costs/benefits to include and which stakeholders to include – a primary driver of such a boundary will be the interests/remit of the party undertaking (or commissioning) the study. Selecting to exclude particular cost/benefits or weighting the interests of some stakeholders differently to others (such as discounting non-GB stakeholder welfare) can yield very different results even when methodologies and other assumptions on market/policy factors are very similar.

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11 'Dash for Interconnection', Aurora Energy Research, February 2016 **[REF4]**

12 Much of the literature on interconnectors highlights that the assets can be expected to vary flow on an hourly basis, and as such the impact varies each hour.
A single interconnector could therefore be expected to have a negative socio-economic welfare impact on consumers in some hours and a positive impact in others. Studies tend to report on the net benefit to across all hours in a given period.

3.2.2 Re-distribution of welfare from transfer elements

In addition to welfare effects caused by movements in wholesale prices, the welfare impacts interconnectors can have on various stakeholders are also affected by a number of transfer elements. These can include low carbon support payments, capacity market payments or ancillary services.

Interconnector flows can lead to differences in low carbon support payments required from GB consumers. Such differences arise in the short- and long-term.

In the short-term, as renewables will be mainly supported through Feed-in-Tariffs under the Contracts for Difference (CfD FiT), the amount of low carbon support payments paid to generators is linked to the wholesale electricity price. When interconnector flows affect wholesale electricity prices, they also affect the amount by which supported installations need to be 'topped up'. If interconnection lowers the wholesale price received by a generator supported through the CfD FiT scheme, payments would need to increase to compensate, and vice versa. However, it should also be noted that:

- low carbon intermittent generation (such as wind farms) tends to be less impacted by wholesale price changes from interconnection than other generators[13]; and
- as only a portion of the market is supported by CfD FiTs at any one time any fall in wholesale prices will still represent an overall gain to consumers;

In the longer-term, interconnectors (or renewable import / export cables) can allow access to cheaper sources of renewable generation, which can potentially alter the total amount of support required. In an analysis carried out for the Policy Exchange, Frontier Economics found that for an extra GW of interconnection, the cost of meeting carbon emissions targets could be reduced by up to £115m per year, given a price of £30/tCO_2[14].

By participating in the capacity market, interconnectors could reduce revenues for generators, which would then be captured by the interconnector operator. If interconnectors merely replace another capacity provider in the auction, this is a transfer element between the interconnector owner and GB generators. If it affects the clearing price, however, it would further reduce producer surplus in the capacity market, which would be transferred to GB consumers.

In a similar fashion, interconnectors could reduce revenues for domestic providers of ancillary services if they are able to replace some of these providers in supplying frequency response, fast reserve or other system services.

As interconnectors can have divergent effects on stakeholders between countries, a mechanism could be needed that re-distributed costs and benefits in a way that any country can benefit. Such cross-border cost allocation (CBCA) mechanisms are considered in ACER's proposed CBCA methodology [15].

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13 Interconnection tends to increase capture rates of wind farms, i.e. the average price captured by a wind generator in comparison to a baseload generator.

14 'Getting Interconnected', Policy Exchange, June 2014 **[REF7]**

15 'Recommendation on good practices for the treatment of the investment requests', Agency for the Cooperation of Energy Regulators (ACER), December 2015 **[REF8]**

3.3 Factors driving interconnector arbitrage value

3.3.1 Categories of factors

The absolute amount and the distribution of costs and benefits between stakeholders and countries are affected by a number of different factors. The following sub-sections introduce these factors and highlight whether the impacts of interconnection on the GB economy are likely to increase or decrease over time.

The following factors are split into market factors, policy and regulatory factors, and technical factors:

- **Market factors** influence prices in the connected markets directly, such as fuel prices or demand patterns. These are introduced in Section 3.3.2.
- **Policy and regulatory factors** influence the way in which markets operate (such as capacity mechanisms) but can also impact interconnectors directly (e.g. transmission charges). These factors are described in Section 3.3.3.
- **Technical factors** are characteristics of the interconnector that influence the way they can participate in the market 3.3.4.

3.3.2 Market factors

Market factors directly impact prices in the connected markets and therefore affect price level differences, shape differences and volatility between the markets.

These factors mostly influence a specific type of arbitrage opportunity between markets:

- **Commodity and carbon prices**[16]: Price level arbitrage opportunities are mainly affected by fuel and carbon prices.

  As the differences in these prices between markets are relatively stable and predictable, this generally leads to price differentials that occur in the majority of periods (i.e. when thermal generation is on the margin).

  While CO_2 emissions are traded on a European basis and there are no differences in the market prices for carbon, the UK CPS creates an effective difference, which is further discussed as a policy factor in Section 3.3.3.

  Commodity prices are already similar between GB and its neighbours, while the differences are often systemic and unlikely to disappear in the future (e.g. transportation costs).

- **Demand patterns**: A main driver for shape value of interconnection lies within the difference in daily demand patterns between two countries.

  Price levels usually follow demand over the day, so differences in demand patterns between two markets can create price differentials. These patterns are determined by industrial activity and consumer behaviour. As these are factors that are unlikely to change in the short- to medium-term, the shape level is likely to be maintained over time.

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16 We note that carbon is described as a commodity here but any form of carbon pricing (be it a carbon tax or carbon market) is by nature policy driven as the price will be set by policy decisions.

This can be observed for example in morning hours, when demand in European hours starts to increase before 6am, while the increase occurs after 6am in GB. This is due to behaviour of households (waking up, start using appliances) and shop opening hours. Additionally, in the case of GB connecting to continental Europe, the time difference adds another hour to this difference.

Industrial activity is more evident in demand patterns of smaller countries, where industrial demand has a greater share in total demand. In these markets, the demand profile will be much flatter, with a less pronounced difference between day and night.

- **Tightness of the system and scarcity rent**: Assuming that electricity generators are unable to recover all their fixed and capital costs by bidding their short-run marginal costs in the electricity and/or capacity markets, they will attempt to bid up in certain periods to capture extra revenues. Usually, this behaviour occurs in periods when the system is relatively tight (due to high demand, low intermittent output). The tighter the system, the higher this 'scarcity rent' element is expected to be. Higher scarcity rent increases interconnector impacts and revenues, especially if tight periods do not coincide between the connected markets.

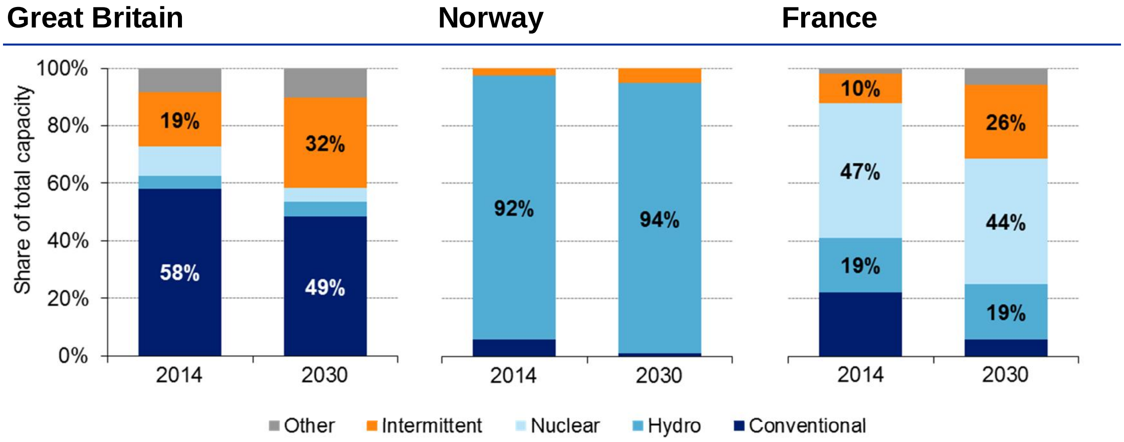
  At present, electricity systems in continental European markets tend to be loose compared to the GB market. Therefore, scarcity rent and price volatility is comparably low. While market fundamentals would dictate this overcapacity to diminish over time, the introductions of capacity mechanisms will shift revenue way from wholesale power prices and could even prevent systems from becoming much tighter, restricting the upside for interconnector arbitrage value.

  For a description of the interaction between scarcity rent and capacity mechanisms see Section 3.3.3.

The remaining two factors can influence all types of arbitrage opportunities between markets:

- **Generation capacity mix (in particular the amount of low marginal cost and intermittent generation installed)**: The benefits of interconnection tend to be higher when the two connected markets have very different generation capacity mixes. This can be observed by investigating different technologies' shares in total power generation (e.g. gas and coal combined for 57% in GB in 2014, while hydro provided 108% of Norwegian domestic demand). In cases where differences are less obvious from looking at generation shares, analysing marginal plants offers additional insights. Differences in the number of periods that certain technologies are on the margin in connected markets indicate fundamental differences in how the generation mix operates which lead to consistent price differentials.

Figure 2 – Capacity mix evolution in selected markets



Sources: 2014 values: Eurostat; 2030: ENTSO-E Vision 1

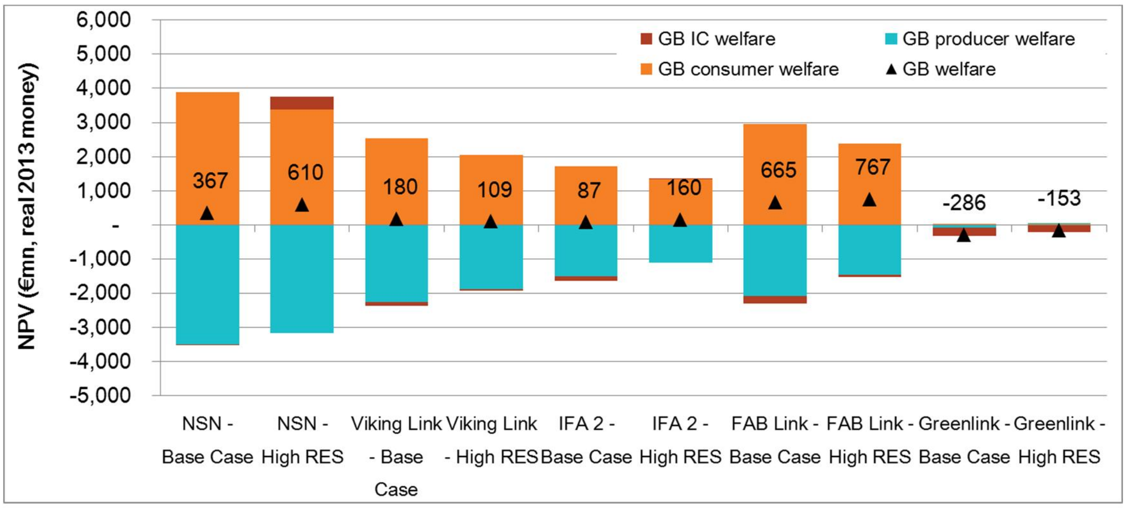
An observation from studies is that higher levels of intermittent generation in one or both markets tend to increase the overall socio-economic case for interconnectors. This is due to more volatile prices on both sides, leading to flows and values over and above the price level and price shape elements.

While the installed capacity mix is stable in the short-term, the growing share of intermittent generation sources makes this factor increasingly unpredictable due to the dependency of these sources on the weather. This leads to more volatile prices and uncertain directions of flow on the interconnector. While volatility tends to increase the economic value of the interconnector, this uncertainty negatively affects the business case and financeability of an interconnector project.

Sensitivity analysis in Pöyry's CBA report for Ofgem finds that for a high renewables case in GB, the GB welfare impact for all but one project improves significantly (between £71m/GW and £266m/GW, NPV, real 2013 money), as shown in Figure 3[17]. However, as the interconnectors tend to be used to export renewable energy and therefore raise prices in windy periods, this increase is largely beneficial to GB producers and, before including welfare transfer elements such as those discussed in 3.2, at the expense of GB consumers.

17 'Near-term interconnector cost-benefit analysis, December 2014 **[REF9]**

Figure 3 – Impact of increased RES penetration in GB in Ofgem analysis



Source: Ofgem / Pöyry Management Consulting

- **Other interconnectors**: The level of existing, or planned, interconnection serving a market is a major driver of the impacts of interconnectors. As increased interconnection tends to bring prices closer together, the impact of each further link is likely to be less positive than the previous.

  Given the significance of decreasing marginal benefits, it is presented separately in Section 5.1.

3.3.3 Policy and regulatory factors

Policy and regulatory factors driving interconnector benefits can also impact either the total value of an interconnector project (if they impact one or more types of arbitrage opportunity), or the distribution of welfare effects between stakeholder groups. These include:

- **Capacity mechanisms**: Making capacity payments available to generators decreases their needs to recover capital and fixed costs in electricity markets. Therefore, the scarcity rent element of electricity prices, as described in Section 3.3.2 is expected to be lower and with it peak prices, thus diminishing the volatility value of the interconnector.

  While the implementation of capacity mechanisms on both side of the link is likely to decrease the value of interconnection available from the wholesale electricity market, interconnector investors can benefit from capacity payments if allowed to participate in the mechanism.

  A 2013 Pöyry study using DECC assumptions at the time found that the capacity mechanism in GB and associated decrease in electricity prices could lead to a reduction in interconnector revenues in the order of 15%-20%[18].

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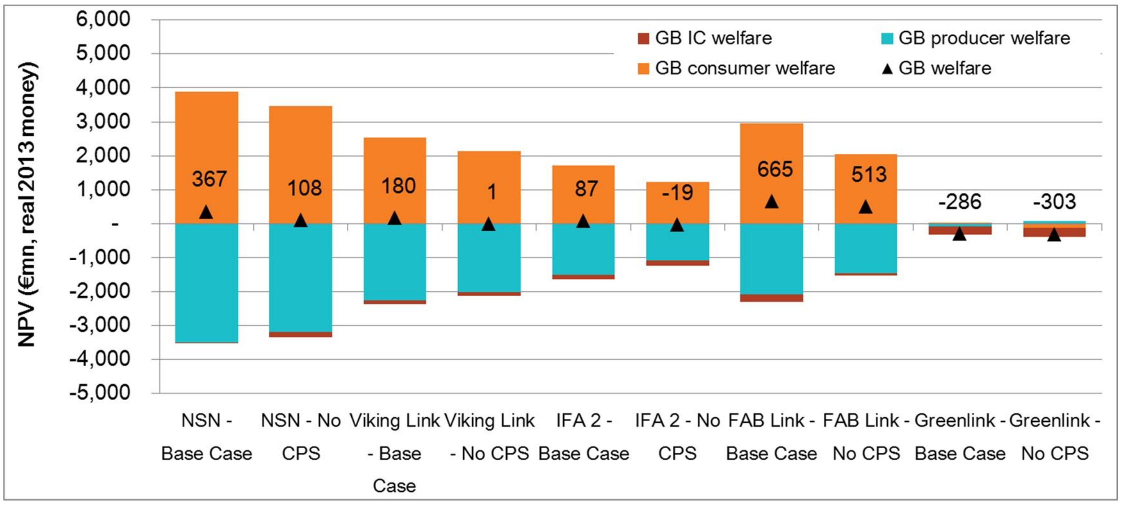
18 'Impact of EMR on interconnection', Pöyry, December 2012 **[REF10]**

- **Carbon taxation**: Differences in carbon prices can create price differentials, increasing both the potential revenues for interconnectors and potential socio-economic welfare benefits introduced by the interconnector.

  Currently, there is a large difference between GB and other European carbon prices from the UK CPS scheme. Removal of the CPS would lower these benefits. This can be observed in Pöyry's CBA study for Ofgem's near-term interconnector applications: all projects perform worse in a 'No CPS' sensitivity compared to the Base Case, as the value to GB is around £100m to £180m lower (NPV, real 2013 money). However, even when removing the CPS, all projects that presented a benefit to GB consumers in the Base Case remain beneficial, and three out of four remain beneficial to GB overall.

Figure 4 – Impact of removing CPS on GB welfare in Ofgem analysis



Source: Ofgem / Pöyry Management Consulting

A difference in carbon prices also affects the impact of interconnectors on dispatch decisions. Therefore, the UK CPS could lead to economically and environmentally sub-optimal solutions when the interconnector is used[19].

An alternative approach to measure the impact of carbon price differentials as taken by Aurora[20] is to add lost taxation revenue as an impact (i.e. include treasury as a stakeholder) to estimate the potential inefficiency in dispatch decision caused if such a policy differential was maintained. Using this approach gives a larger effect of ~£400-£500m per GW.

- **Transmission and balancing charges**: Similar to carbon taxation, a difference in transmission charges between two markets can lead to distortions in operational decisions and potentially cause sub-optimal dispatch.

19 The CPS could lead to a situation where an otherwise cheaper (and cleaner) source in GB would be replaced in the dispatch by a source in continental Europe, which does not face the CPS. However, even in this situation the interconnector flow may have a positive welfare effect as it reduces the overall costs faced by generators (at the expense of higher carbon emissions).

20 'Dash for Interconnection', Aurora Energy Research, February 2016 **[REF4]**

In GB, interconnectors are not charged the respective generation or demand tariff, potentially favouring non-domestic plant over domestic generators. This has been criticised by industry participants in consultation responses to Ofgem's cap and floor decisions and the National Infrastructure Commission's November 2015 call for evidence. Harmonisation of these charges on a European level is possible, which would reduce the price level value of the interconnector.

This is discussed in a recent report by CEPA prepared for ACER[21]. The report finds that non-harmonised transmission tariff structures could theoretically distort both operational and investment decisions, especially with regards to generation, and could thus lead to inefficiencies. However, CEPA finds no direct evidence for investment impacts of non-harmonised tariffs, although indications of potential distortions exist. Finally, CEPA also recognises that differing national taxation, support schemes or planning restrictions can have a far greater influence on these decisions.

However, a study conducted by Frontier Economics[22] estimates that the lack of harmonised generation tariffs could increase the cost of capital of potential investors by as much as 0.5%, due to the perception of increased regulatory risk.

In addition, Aurora highlight that differences in system charges between countries that interconnectors would be exempt from, could create inefficiencies or higher costs to domestic stakeholders. According to their report, this is primarily driven by "the large welfare cost associated with network charge exemptions for interconnectors, which accounts for more than half of the total subsidy cost of all projects."

- **Low carbon support mechanisms**: Payments for low carbon generators do not affect interconnector flows and therefore have no impact on the overall benefit provided by the interconnector. However, as interconnectors have an impact on the amount of these payments, value transfers between stakeholders are triggered by interconnector flows.

  GB consumers are affected when interconnector flows change wholesale electricity prices. However, not all price movements will directly impact consumers. The CfD FiT scheme for low carbon generators requires consumers to top up wholesale revenues for low carbon generators. Thus, to the extent interconnectors change revenues that CfD FiT supported generators earn in the market, consumer welfare is not impacted. For producer welfare, the same is true for the revenues of these CfD FiT supported generators.

  More broadly, low carbon support schemes are not harmonised across Europe nor are targets set for members to optimise the location of low carbon generation. ENTSO-E's studies conclude that large increases in interconnection would be beneficial to a lower cost path to decarbonisation. This highlights the issue that such climate policy inefficiencies can create a risk of under- or over-investment in both certain types/locations of generation assets (and by implication interconnection). .

- **Support mechanisms and regulatory regimes for interconnectors**: Another purely distributional factor is government support for interconnectors.

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21 'Scoping towards potential harmonisation of electricity transmission tariff structures', CEPA, August 2015 **[REF11]**

22 'Transmission tariff harmonisation supports competition', Frontier Economics, 2013 **[REF12]**

Under Ofgem's cap and floor regime, interconnectors will need to return revenue over the cap to GB consumers, while consumers will need to top up the interconnectors' revenues when these fall below the floor. While this does not affect the overall socio-economic welfare impact of a project, it represents a potential transfer element between the interconnector and GB consumers.

3.3.4 Technical factors

Some of the technical factors that can influence interconnector cost benefit elements are:

- **Thermal losses**: Transmission losses on the cable dictate the minimum price differential needed between two markets in order for flow on the interconnector to be economically viable. In case of a 5% loss factor, for example, market participants need to source 105MWh on the exporting side, to be able to sell 100MWh on the other side. Therefore, a smaller loss factor allows the cable to increase the periods when it will flow, and therefore its impact on socio-economic welfare.

  The losses on interconnectors occur during conversion and transmission. According to a major cable manufacturer, the estimated loss on an HVDC line is 0.9% per 100km plus 1.5% (regardless of length) to account for losses during conversion. On this basis, interconnector projects serving GB have expected loss factors between 2% and 10%.

- **Availability**: The greater the availability of an interconnector, the larger the potential impact on socio-economic welfare. Given that cable and converter failures occur randomly, it is difficult to estimate the impact of lower availability on the costs and benefits of a project.

- **Technology choice**: Technical innovation has led to an extension of the services interconnectors can provide, especially frequency response and black start capability. While these new technologies are unproven and tend to be more expensive, the revenues gained and extra benefits provided could be important for projects that otherwise only show marginal commercial gains or socio-economic welfare benefits.

- **Capital and operational costs**: Interconnectors are capital-intensive projects with investment costs ranging between €2m and €4m per GW and km. Whether an interconnector can provide a net benefit to socio-economic welfare depends on whether its net impact on consumers and producers outweighs its costs.

3.4 Conclusions on interconnector impacts on costs and efficiency

All of the factors above vary between the different markets that GB could connect to, based on the type of arbitrage opportunity there is with that market (price level, shape or volatility), on the policies affecting interconnectors in the markets, and on technical factors. Therefore, the direction of the interconnector is a fundamental driver of its impact and value. For each of the currently connected countries and possible future connections, the size and outlook for these arbitrage types in the future are described in Table 4.

The evidence examined suggests that connecting to some markets brings large net benefits across a wide range of market scenarios across studies with multiple boundary conditions.

As an example, Redpoint has found that connecting to hydro-intensive markets, such as Norway and Iceland provides large benefits in all scenarios[23]. A case with 4GW interconnection to these markets by 2040 provided around £900-6,500m higher benefits (real 2012 money, NPV) than a case with only one 1GW link to Norway.

The same study finds that in the medium-term, another interconnector with Ireland may be appropriate, as it provides between £150m and £650m extra benefit over only reinforcing the French interconnector. In a case with low fuel prices and high flexibility in GB, an additional Irish interconnector reduces the result by £200m.

23 'Impacts of further electricity interconnection on Great Britain', Redpoint, November 2013 **[REF13]**

Table 4 – Outlook for interconnector value drivers across markets

Connected market	Arbitrage opportunities			Policy and regulatory environment	Costs
	Price level	Price shape	Volatility		
France	currently large, decreasing if CO_2 price difference decreases (CPS)	time difference, overnight difference due to French nuclear share	installed capacity of intermittent sources increasing from 10%[24] to 26%[25]	capacity market	short distance, relatively low capex
SEM (Ireland)	medium, close to zero without CPS	small	intermittent RES increasing from 31% to 45%	capacity market	short distance, relatively low capex
Netherlands	same as France	time difference	intermittent RES increasing from 14% to 36%		short distance, relatively low capex
Belgium	same as France	time difference	intermittent RES increasing from 24% to 40%		short distance, relatively low capex
Norway	large	flat prices in Norway due to hydro dominated system	expected to remain low to moderate		long distance, relatively high capex
Denmark	currently large, decreasing without CPS	time difference, access to Nordic hydro storage	intermittent RES increasing from 3% to 56%		long distance, relatively high capex
Iceland	Iceland currently does not have a spot market for electricity. As all of its electricity is generated by hydro, geothermal and wind sources, none of which have short-run marginal costs, prices would be set by a different metric (or negotiated via a power purchase agreement). Given the abundance and low cost of this electricity, an interconnector with Iceland would be expected to be a baseload importer.				long distance, relatively high capex

24 All 2014 values from Eurostat

25 All 2030 values from ENTSO-E Vision 1 (TYNDP 2016)

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4. OTHER INTERCONNECTOR IMPACTS

4.1 Impacts on security of supply

Interconnectors can affect societies and economies by impacting security of electricity supply, defined as "the ability of a power system to provide an adequate and secure supply of electricity in ordinary conditions" (ENTSO-E guidelines).

Security of supply is at the forefront of both European and GB energy policy. The EC intends to propose new legislation on electricity security of supply in 2016, as part of its Energy Union Strategy. In GB, DECC has introduced a capacity market to ensure that security of supply is maintained for GB consumers. The most recent GB Capacity Market auction enabled interconnectors to participate and offer capacity on the same terms as existing generation capacity[26] (i.e. with an applied derating factor to their capacity to reflect their likely availability at times of system stress). Two interconnectors were successful in this auction round, contributing just over 4% (1.8GW) of the overall capacity requirement procured (46.4GW)[27].

The de-rating factors for interconnectors have been calculated by reference to expected price differentials between the interconnected markets during stress periods, with the assumption that flows will reflect price differentials. Concerns have been raised, that insufficient de-rating could create inadequate procurement of capacity in auctions (e.g. by Energy UK)[28]. However, it has also been argued that on the other hand, overly conservative de-rating factors could lead to excessive procurement of capacity and therefore unnecessarily high costs for consumers[29].

Historical analysis suggests that interconnector flows have not always responded in an economically rational manner, leading some to question the impact of interconnectors on security of supply (i.e. that by displacing domestic generation they worsen our security of supply because they are less reliable sources).

However, in work for DECC[30] Pöyry analysis showed that over the last few years the economic response of interconnector flows to price differentials had improved significantly with respect to the French and Netherlands interconnectors (see Figure 5). This has largely been attributed to the improved rules regarding market coupling and cross border capacity allocation through the system of European Network Codes that are being introduced.

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26 Indeed across Europe where interconnectors are traditionally seen as transmission network assets their primary justification has been ensuring reliable supply. In GB however interconnectors are generally treated as generation and demand and as such are included in capacity planning and the GB capacity market.

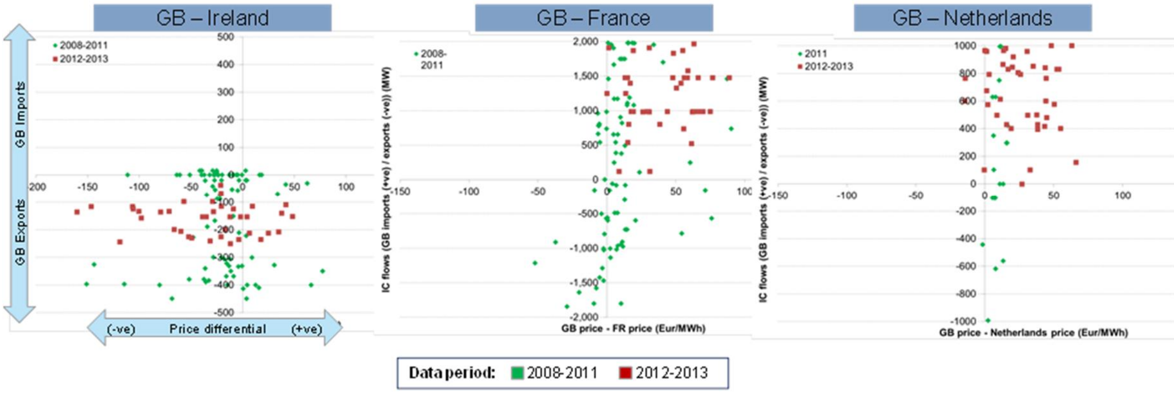
27 'Final Auction Results, T-4 Capacity Market Auction for 2019/20', EMR Delivery Body, December 2015 **[REF14]**

28 'Response to DECC consultation on Capacity Market supplementary design proposals and Transitional Arrangements', Energy UK, November 2014 **[REF15]**

29 'The Final Hurdle?: Security of supply, the Capacity Mechanism and the role of interconnectors', University of Cambridge Energy Policy Research Group, September 2014 **[REF16]**

30 'Historical approaches to estimating interconnector de-rating factors', Pöyry/DECC, February 2015 **[REF17]**

Figure 5 – Correlation of interconnector flows with price differentials



Nevertheless, to the extent that interconnectors are not de-rated sufficiently there may be under-procurement of capacity within the capacity mechanism. This may occur because of the uncertainty over future price formation between markets, meaning that even if flows are economically rational, the out-turn prices in markets may differ from those used to calculate the de-rating factors. In essence, future prices are less predictable than the technical reliability of a power station. To mitigate this risk, DECC has created a conservative de-rating approach for interconnectors. In the 2015 t-4 auction, proposed factors ranged between 6% and 69%[31], although not all interconnectors participated.

Note that many studies often assume a constant security of supply standard by varying capacity in the counterfactual based on assumed or modelled contribution of interconnection. This can be an important driver of efficiency gains (see Section 3) and reflects the current expected behaviour of interconnectors in the capacity market. However, using an alternative approach where capacity is kept constant some stress test scenarios can be modelled and literature reviewed in this area shows a potential positive impact on security of supply, using the metric of expected energy unserved.

In Redpoint's 2013 study for DECC, two stress tests assuming (1) coinciding low wind output, high demand periods and unplanned plant outages and (2) rapid wind output changes coinciding with line outages concluded that additional interconnection generally leads to lower expected energy unserved. At these times, interconnectors from most countries were importing to GB for >97% of the time, except for French interconnectors, that were importing 84-99% of the time.

In a 2013 report for Ofgem, Pöyry has found that while low capacity margins in GB (<20%) show a medium level of correlation with Irish and French low capacity margins, interconnector flows have generally helped reduce the number of low capacity margin hours in a year. For very low capacity margins (<10%), no definite correlation has been found and interconnector flows have neither helped nor worsened these conditions in GB.[32]

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31 'Confirmation of capacity auction parameters', DECC, June 2015 **[REF18]**

32 'Analysis of the correlation of stress periods in the electricity markets in GB and its interconnected systems', Pöyry, March 2013 **[REF19]**

4.2 Environmental and social impacts

Interconnectors can have a number of different effects on the environment and on social factors in GB. Some of these factors, such as CO_2 emissions and electricity sector decarbonisation are at least partially internalised in cost-benefit assessment studies as they are reflected in system costs.

However, there are additional elements that are usually not included in the socio-economic welfare. These elements can be split into impacts that arise in association with flow (and therefore are a result of price arbitrage) and impacts that emerge from an interconnector being built and operated.

Elements in the first group are:

- additional impacts on electricity sector CO_2 emissions not reflected in system costs – these will include wider societal benefits/costs of changes in CO_2 emissions[33]; and
- impacts on CPS and other variable tax revenues leading to tax losses or gains to treasury (as discussed in section 3.3.3).

As regards the market cost of CO_2 emissions, this impact is already taken into account in assessing efficiency savings on the electricity system. However, an efficiency increase in system dispatch does not necessarily mean a decrease in CO_2 emissions. If the carbon price is low, or the difference between GB and European carbon prices is high, it may be economically more efficient to operate a more polluting plant over a cleaner plant. In a 2014 report[34], the Policy Exchange recognises this adverse effect and warns about the risk that this could lead to a 'race to the bottom' in carbon pricing systems. In fact, the UK government capped the CPS in its 2014 budget, creating lower effective carbon prices in the UK in the medium-term.

The second group of additional impacts, not linked to flow on the interconnector, includes:

- direct local environmental effects; and
- job creation (during construction and ongoing) and broader social effects; and
- effects on the local and wider economy (such as connected industries).

There have been concerns raised over the environmental impact of marine interconnectors. All new interconnector projects will have a non-zero environmental footprint, even when mitigated. and these aspects would need to be taken account in the project assessment. Interconnector projects consist of land and sub-sea cables, transformers, converter stations and other elements, all of which may impact the local environment. During construction, local stakeholders are affected by visual disamenity, noise, vehicular pollution and transformation of the surrounding environment. After construction, some impacts remain, such as noise and heat emissions. The choice of technology for interconnectors also affects the environmental impact (Voltage Sourced Converter vs. Line-Commutate Convertors).

33 It is noted in the ENTSO-E Guidelines for Cost Benefit Analysis of Grid Development Projects that this societal benefit could be included using a societal cost of carbon but such practice does not appear widespread from the literature.

34 'Getting Interconnected', Policy Exchange, June 2014 **[REF7]**

However, one should also consider the potential displacement of other investments (power plants, other transmission assets), which could potentially have a higher social and environmental impact. Therefore, the net social and environmental impact of interconnector projects can be positive or negative.

4.3 Harder-to-quantify impacts of interconnectors

There are several impacts interconnectors have on the wider society that are harder to quantify and as such are often neglected or overlooked in the literature (or at least where mentioned are rarely quantified). The most prominent of these are:

- **Market power and competition:** Interconnectors can improve competition by effectively creating larger markets. If players hold pivotal roles in a market in certain periods, they can influence prices to levels higher than their costs of generation. By connecting two markets, generators on both sides compete with each other, which could lead to prices better reflecting the actual cost of generation. To the extent that this actually leads to better dispatch decisions, this constitutes a welfare gain, while simple price reduction only leads to a welfare transfer from producers to consumers.

  The counterarguments to the benefit interconnectors can provide for competition are:
  - Players with a certain degree of market power on both sides of the link could use the interconnector to strengthen their power.
  - In the event the interconnector displaces a power plant development by an independent party, competition could be negatively affected.

  In 2011, Brattle analysed NEMO's effect on the competition and market power in the GB market. The analysis found that if NEMO's capacity was used by independent players, HHI would decrease by around 2.4%. It is also estimated that if the capacity on the interconnector that a single company controls is limited to 43%, a beneficial impact on GB competition is highly probable[35].

- **Market liquidity**: Interconnectors add another source of supply to two markets, potentially increasing liquidity in both. As with other factors, this impact should be compared to alternative investments' impacts on this factor.

- **Market design**: Cross-border trading could potentially create new markets between countries. A European single electricity market is only possible if there is sufficient interconnector capacity. Therefore, interconnectors can be regarded as enablers for future market design options.

35 'The "Nemo" interconnector. Estimates of impact on TSO revenues, welfare and competition', The Brattle Group, February 2011 **[REF20]**

5. ADDITIONAL CALL FOR EVIDENCE CONSIDERATIONS

In addition to the core work scope of examining the costs and benefits of interconnection by drawing on the existing evidence base, the National Infrastructure Commission call for evidence raises two additional questions, addressed below:

- What are the interactions between interconnectors and what does that tell us about reaching a theoretical optimum level of interconnections? (Section 5.1); and
- How might interconnectors interact with other potential sources of flexibility? (Section 5.2)

5.1 Interactions between interconnectors and reaching a theoretical optimum

5.1.1 Changing arguments for cross-border transmission

The majority of studies, documents and commentaries reviewed for this report take a positive view of additional interconnection serving GB. Benefits can be identified for a number of additional projects and policies appear to be in place to deliver these projects.

Considering the impact that these new projects may have on existing interconnectors, and on each other, the evidence base shows that:

- cannibalisation occurs between interconnectors (i.e. diminishing returns and socio-economic value[36]), even when not connected to the same market; and
- the level of cannibalisation depends on the market connected, based on the type of arbitrage opportunity with that market (see Section 3.4).

5.1.2 Theoretical 'optimum' of interconnection

There is no consensus around how much additional interconnection would be appropriate for GB given the level of uncertainty around future market conditions and cost competitiveness of alternative technologies. However, all studies reviewed agree that there were potential benefits to GB from at least some additional interconnection beyond the current level.

Using scenario analysis, it is theoretically possible to determine an 'optimal' level of interconnection either between two particular markets (e.g. between Britain and France) or for all interconnector serving one market (e.g. Britain and surroundings). However, this is complex and potentially controversial, as a number of questions need to be answered in order to perform this assessment:

- **What are the boundary conditions in the assessment?** – Projects that appear detrimental to single jurisdiction could actually beneficial to the wider system, and vice versa. Selecting the parameters of a study (e.g. geographical scope, assessment cases) is central to ensuring a valid and robust assessment.

36 Pöyry's 2014 CBA for Ofgem for example found that consumer benefits of the French interconnectors assessed would be 10-15% greater if the build of the second French interconnector was delayed by 15 years.

- **What metrics are taken into account?** – There is a long list of costs and benefits associated with interconnectors, as discussed in Chapter 2. The outcome of the assessment depends on which of these metrics are taken into account.
- **What assumptions are taken for the future?** – Scenarios assessed can differ in a wide variety of ways, such as fuel prices, demand, generation capacity, renewables roll-out and carbon policy. Any assessment will only result in an optimum for a specific case. To develop a lest-regret case, numerous combinations of interconnector build scenarios need to be combined with different market scenarios.

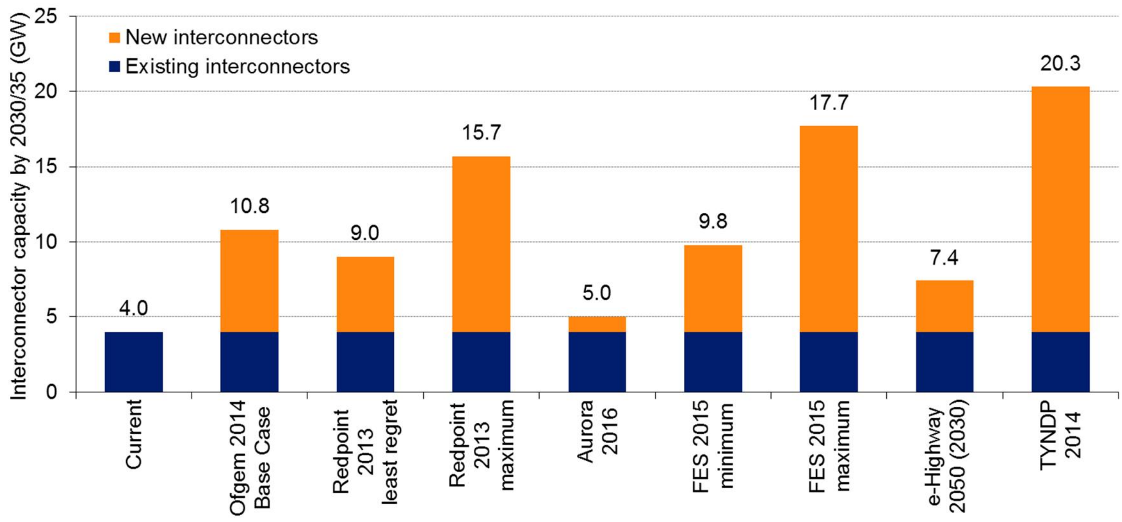
The existing literature can provide some hints towards an optimal interconnection level. Key messages drawn from the evidence base can be summarised as follows:

- All studies show beneficial expansion scenarios of specific interconnectors based on socio-economic welfare analysis, including impacts on consumers, generators and interconnector owners (which include capital cost of the assessed projects).
- The amount of additional interconnection to GB until 2030/35 that provides benefits to either GB or the overall system varies between 1.0GW and 16.3GW for a total interconnection capacity of 5.0GW to 20.3GW, as shown in Figure 6. Specifically:
  - in Pöyry's analysis for Ofgem, the four projects with a positive impact on GB provided between €0.1bn/GW and €0.7bn/GW (NPV, real 2014) socio-economic welfare benefit to GB;
  - in Redpoint's analysis for DECC, the least-regret solution (+5GW until 2035[37]) provides between £0.3bn and £1.6bn of benefits to GB, depending on the scenario. Redpoint's maximum interconnector combination of 15.7GW did not appear to be the highest possible beneficial combination in some scenarios, indicating some circumstances in which even more interconnection could be considered;
  - according to Aurora's analysis, only interconnection to Norway would be beneficial to GB, as it would provide a net benefit of £0.1bn/GW;
  - while National Grid's Future Energy Scenarios (FES) 2015 do not specifically refer to a socio-economic welfare analysis, they assume that between 5.8GW and 13.7GW of new interconnection is commissioned by 2030;
  - the e-Highway2050 project focused on the grid development post-2030, but assumed additional 3.4GW of additional interconnection capacity to GB (1.0GW to France, 1.0GW to Belgium and 1.4GW to Norway) before that point; and
  - in ENTSO-E's Ten-Year Network Development Plan 2014 (TYNDP), the total capacity of interconnection serving GB is 20.3GW, including links to most North-West European countries and even Spain. While no full CBA result is provided, ENTSO-E explains that "The TYNDP 2014 explains how ENTSO-E proposes to integrate by 2030 up to 60% of renewable energy, respecting cost-efficiency and security through the planned strengthening of Europe's electricity power grid."[38]

[37] Consisting of: 500MW to Ireland and a further 500MW in 2035; 1,000MW to France in 2020 and a further 1000MW in 2035; 1,000MW to Belgium in 2025 and 1,000MW to Norway in 2030.

[38] '10-Year Network Development Plan 2014', ENTSO-E, October 2014 **[REF2]**

Figure 6 – Levels of GB interconnection assessed in different studies



Source: Ofgem, Pöyry, Redpoint, Aurora, National Grid, e-Highway2050, ENTSO-E

- The variation of results within this range is primarily based on varying boundary conditions and different assumptions regarding the future market and policy environment in GB and wider Europe:
  - higher interconnection capacity is beneficial when assuming especially ambitious renewable expansion cases or a particularly large difference between GB carbon prices and EU ETS prices[39].
  - the benefit of interconnection expansion is more limited when assuming lower fuel prices and a low CO_2 price differential.
  - when incorporating the value of ancillary service provision in the decision making, an even greater amount of interconnection could be accommodated, especially between GB and Ireland[40].
- Diversification of interconnection is beneficial if there is a large price level value with most countries or high penetration of intermittent renewables. Redpoint's study shows that in these cases (Scenarios 1 and 2) connecting GB to nine different markets provides additional benefits of £200-1,200m (real 2012 money) over connecting to three markets only with similar total capacity. In cases with lower renewables and a lower carbon price differential (Scenarios 3 and 4), no positive difference was found (as shown in Table 5).

39 Without the offsetting inclusion of falling taxation receipts as assumed in the Aurora analysis.

40 'Understanding the Balancing Challenge', Imperial College London and NERA for DECC, August 2012 **[REF21]**

Table 5 – Socio-economic welfare impact on GB (£m NPV, real 2012)

Configuration	Scenario1	Scenario2	Scenario3	Scenario4
9 markets, 7.4GW	2,906	700	-832	-77
7 markets, 8.6GW	2,856	732	-606	188
6 markets, 8.1GW	2,095	498	-261	305
5 markets, 8GW	2,416	254	850	290
3 markets, 7.6GW	1,625	515	59	387

Source: Redpoint

5.1.3 Barriers to achieving increased interconnection

A target for EU member states to achieve an installed level of interconnection equivalent to 10% of their installed generation capacity was first set in 2002 for the year 2005. However, in 2014, this target was still only being met by 16 member states and governments are unlikely to set specific and binding targets[41].

The 10% target is supported by many of stakeholders in principle, however, it has been criticised for being arbitrary and lacking relation to the specifics of different markets (e.g. GB and Ireland as island markets requiring more expensive sub-sea DC interconnection as opposed to short, AC overhead cables in continental Europe). Additionally, a target referring to installed capacity appears to neglect the fact that all generation capacity cannot be treated equally (e.g. considering an average availability of >80% for CCGT compared to 10% for solar PV in Great Britain).

It is unclear whether any form of national GB target (binding or indicative) would boost or hinder the government's goal of maintaining a secure, affordable and low-carbon energy system. While increased interconnection is generally viewed positively, the majority of recent evidence suggests that current policies are regarded as sufficient (or indeed that support is too extensive in some cases).

Moreover, it is questionable whether an explicit target for interconnection is appropriate, given the fact that it is only one of many possible, and probably complementary, options to manage future energy challenges.

The uncertainty around many of the key factors driving interconnector value means that while saturation points not yet have been reached, a more gradual approach to future development would be appropriate so as to not foreclose markets unnecessarily to other technologies. The more interconnection there is with one specific market, the more consistency in system planning and treatment of interconnectors in capacity markets there needs to be across markets.

The following principles should be considered when designing a regulatory framework for future interconnection:

- insofar as interconnector benefits from wholesale market arbitrage are expected to become more marginal, the regulatory framework should allow interconnectors to

41 'Achieving the 10% electricity interconnection target', European Commission, February 2015 **[REF12]**

compete on an equal footing with other sources of generation or flexibility (e.g. participation in capacity markets and ancillary services markets, treatment of transmission and balancing charges);

- interconnectors should be able to capture the full market value of the investment and any market and policy failures preventing this should be removed;
- where interconnectors are not responding to price signals, projects should be reviewed and potentially not be supported if this is representing an inefficient capacity allocation; and
- projects should be assessed on their impact on socio-economic welfare, system operation and their interaction with other interconnectors. This is a key step in the existing assessment process for Ofgem's cap and floor regime for interconnectors.

5.2 Interconnectors and other sources of flexibility

5.2.1 Future flexibility requirements

Increasing intermittent generation resources and changing demand patterns will lead to greater and more complex needs for flexibility in wholesale electricity markets, due to increased forecast errors. Currently, most of that flexibility is provided by back-up generation, and, to a lesser extent, demand side response and interconnectors.

Acknowledging the growing need for flexibility, the CCC has identified increasing flexibility as a low-regret option, as it could provide benefits of £2.9bn even in a less-ambitious decarbonisation scenario[42].

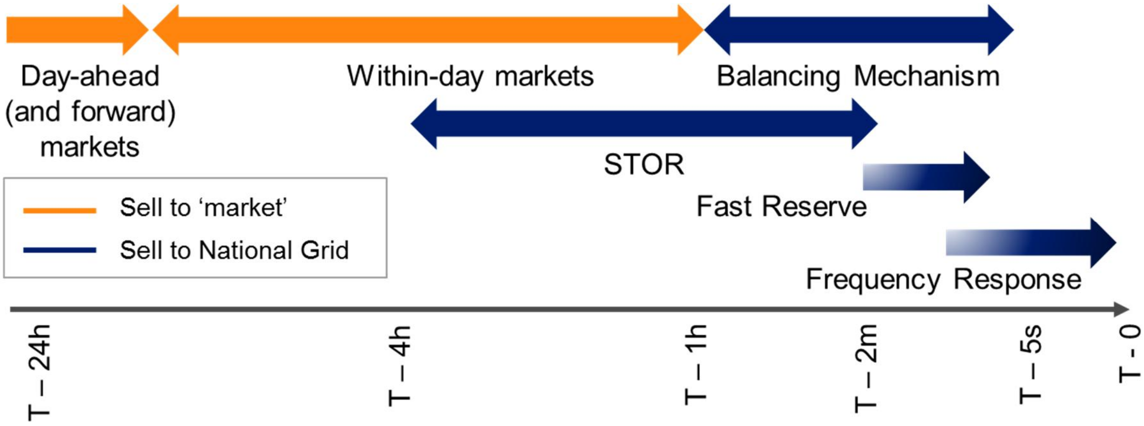
We understand that the NIC are separately considering the wider need for flexibility in their review so we have not provided a detailed breakdown here. However for the purposes of answering the specific call-for evidence question it is useful to split out two types of flexibility requirements in the GB electricity system:

- formal flexibility services, namely the 'ancillary services' procured by National Grid, such as fast reserve, frequency response and black start; and
- flexibility in a wider sense, as required in the day-ahead and intra-day markets.

Figure 7 shows the routes to market for flexibility providers, for both formal ancillary services and wider flexibility.

42 'Value of Flexibility in a Decarbonised Grid and System Externalities of Low-Carbon Generation Technologies', Imperial College London for the CCC, October 2015 **[REF23]**

Figure 7 – Routes to market for flexible generation



Source: Pöyry Management Consulting

Over the course of hours, days and months, requirements for different types of flexibility occur, including the need for peaking energy when demand is high and intermittent generation is low, the need for quick response in the event of a sudden outage, or the need to manage an abundance of intermittent generation on the system, just to list a few.

There is no single technology that can meet all these requirements, hence a combination must be found that deals with the situation in an efficient way.

5.2.2 Characteristics of flexibility options

Different types of sources provide different types of flexibility in the GB market:

- At present, **thermal plant** is the largest source of flexibility, providing response either through varying their output or commencing / ceasing generation. The most flexible generators that are able to provide response quickly are OCGT plant and engines. Thermal plant can provide flexibility over longer timescales.
- Significant amounts of flexibility is currently also provided by **pumped storage (PS)**, with a total capacity of 2.7GW. Plants can respond very quickly making it eligible to participate in most reserve markets. PS is a proven flexibility provider, but has very high investment costs at around £1,700/kW and its short-run cost depend on prices during pumping mode. Length of response periods is limited by the size of the reservoir.
- **Demand Side Response (DSR)** providers help maintain supply-demand balance in short timeframes. This is often provided by large industrial sites or aggregated smaller off-takers that reduce consumption in exchange for payment. DSR has high utilisation costs of typically >£200/MWh.
- **Storage providers** have the potential to play a larger role in providing flexibility services in the future. Batteries can respond very quickly and could be commissioned in up to 50MW installations. Length of response periods is limited. The main factor for storage providers is cost evolution. While the cost of lithium-ion batteries has decreased from more than $3000/kWh in 1990[43] to less than $200/kWh today[44].

43 'Dealing with Divergence', Citi Group, January 2015 **[REF24]**

- **General improvements** in system management and techniques of weather forecasting could mitigate some of the increasing need for balancing services and other flexibility[45]. These improvements could also include grids becoming increasingly 'smart'.

5.2.3 The role of interconnection in providing flexibility

In the future, interconnectors are expected to play a greater role in providing both formal and wider flexibility to the system. Therefore, interconnectors will be compared to and assessed against other source of flexibility in the GB electricity market, namely flexible generation, demand side response (DSR), storage and smarter networks.

In the evidence base, the view of interconnectors as flexibility providers is generally positive, summarised in the following key messages:

- Large amounts of flexibility and balancing technologies will need to be commissioned, especially when considering ambitious renewable expansion targets.
- Interconnectors can technically provide flexibility (such as ancillary services) and this could benefit GB consumers[46].
- In order for interconnectors to unlock the full value of their flexibility, trading of energy across borders and timeframes needs to be enabled.
- Interconnectors can complement other flexibility sources. Even in cases when a large amount of other technologies is commissioned, the system can still benefit from additional interconnection providing flexibility, as interconnectors can provide types of flexibility that other technologies cannot (e.g. sustained flows of large amounts of electricity).

Some of the caveats of interconnectors as flexibility providers is that in any case, providing flexibility on one side of the link inevitably has an effect on the other end as well. In the case of ancillary services, contracts need to be in place on both sides, and the ability to provide services to GB depends on the availability of the service in the connected market. Other stakeholders warn of the possibility of correlated needs for flexibility (due to similar weather in the whole region), which could exacerbate stress situations in GB.

While interconnectors are capable of participating in many formal and wider flexibility markets, it is expected that they will first and foremost seek to play a role in providing baseload electricity. The larger the opportunity for interconnectors to arbitrage in day-ahead and forward markets, the lesser their expected role in ancillary services and balancing markets.

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44 'Crossing the Chasm. Solar Grid Parity in a Low Oil Price Era', Deutsche Bank Markets Research, February 2015 **[REF25]**

45 'Value of Flexibility in a Decarbonised Grid and System Externalities of Low-Carbon Generation Technologies', Imperial College London for the CCC, October 2015 **[REF23]**

46 'Benefits of Interconnectors to GB Transmission System', National Grid, December 2014 **[REF4]**

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6. CONCLUSIONS

Pöyry has drawn upon a range of reports, studies and other publications to form the evidence base for this report. These documents have been reviewed to compile common conclusions on the socio-economic welfare and wider societal costs and benefits of interconnectors serving GB.

Benefits of interconnectors

There is strong agreement that the socio-economic welfare value of interconnectors comes from their ability to improve the efficiency of outcomes in the electricity system, lowering the cost of meeting demand and of achieving other policy objectives such as improving security of supply and enabling more efficient renewables integration.

The overwhelming majority of literature reviewed concluded that additional interconnection beyond current levels is likely to bring significant benefits to the UK. However, whether particular interconnector combinations provide a net benefit to GB and the wider system depends on several aspects:

- the boundary conditions, i.e. which stakeholders are included in the analysis, in which countries and what categories of costs and benefits are included;
- the objective function, e.g. welfare maximisation, cost minimisation, carbon minimisation; and
- the specific market modelling assumptions, e.g. commodity prices, capacity build and future energy policy assumptions.

Therefore comparability between conclusions of studies is hard as while they often look at the same impacts they do it through a different lens. It is important to acknowledge that the majority of studies look at societal benefit, not the incentives on a commercial developer.

Sources of socio-economic welfare value

The socio-economic welfare value of interconnectors comes principally from balancing the capital and operational costs of new connections with cost and efficiency improvements represented by hourly wholesale price differences between markets. Such wholesale price variations between markets provide the key market signals for interconnection and by exploiting these differences interconnectors affect the socio-economic welfare of the system. This wholesale price value can be helpfully differentiated into three main types:

- **wholesale price level value**, where prices differ on an annual average basis i.e. largely intrinsic value as can be traded ahead of time, with future value driven by commodity prices;
- **wholesale price shape value**, where prices differ in their underlying average shape over a period in a way that can be predicted i.e. a mix of intrinsic (i.e. average price differential) and extrinsic value (i.e. hourly price differentials, tradable only very close to real-time due to forward market granularity issues), robust over relatively long-time periods; and
- **wholesale price volatility value**, deriving from unpredictable price peaks and troughs which only appear close to real-time i.e. largely extrinsic value, dependent chiefly on difficult to forecast events and the roll-out of intermittent generation.

In addition, value for certain interconnectors can come from their ability to provide **services to System Operators** (i.e. balancing and ancillary services) and provide **capacity contribution** in one or both markets they connect, represented in GB (and some other European markets) by payments under a capacity market.

The importance of each value source will vary between markets and will also change over time (depending on renewables and storage deployment, electrification of heat and transport, smart grid development, etc.). There are likely to be more persistent arbitrage opportunities with some markets than others. The review suggests a general agreement that the importance of extrinsic value is likely to increase in the future.

Security of supply

Interconnectors can potentially increase the security of supply in one or more electricity systems. However, additional interconnector capacity could displace domestic sources of generation. The net of these effects is uncertain and the impact on both systems will be dependent on the detailed assumptions of a study.

Some of the criticism of interconnectors has been directed at the lack of economic rationality in flows. While this has been an issue in the past, it is less prevalent now with improved market coupling at the day-ahead stage and the structures being introduced under the target model.

The extent to which interconnectors displace capacity in GB depends on how they are treated in the capacity market, especially with regard to de-rating factors and the assessment of required capacity that is procured through the auctions. If de-rating factors are applied appropriately, interconnectors should not be inferior to generation capacity in the capacity mechanism. However, given that these de-rating factors are based on projected price differentials, some uncertainty and risk remains as these projections could be incorrect. This risk is mitigated by:

- using conservative de-rating factors; and
- re-assessing the contribution of interconnectors every year and determining the factors only four years in advance to capture changing market dynamics.

The potential for interconnection to have a complex impact on security of supply highlights some need for harmonisation and coordination between TSOs and Market Designs, which is being promoted by European authorities such as the European Commission and ACER.

Environmental effects

At an EU level, interconnection is seen as a necessary means of achieving a lower cost decarbonisation pathway. Increased interconnection may lead to offsetting impacts on national renewables targets, it may reduce curtailment, making support more efficient and avoiding additional capacity build. If wholesale prices fall due to interconnector flows, this may increase the need for renewable support payments, though the effect on consumers may not be any different.

Some of these benefits could be captured in wholesale prices, thereby providing a market signal for interconnection and allowing for clear inclusion in a CBA. However major policy inefficiencies persist such as differences in carbon costs between countries and a lack of harmonisation of renewable policy support between EU member states. This creates a risk of inefficient flows on the interconnector as well as the potential for over/under-investment in a level of interconnection consistent with a lowest cost EU wide decarbonisation pathway.

Future levels of interconnection

Since interconnectors change prices, decreasing marginal returns from additional interconnection and stronger impacts on other existing interconnectors in the long-term are expected as price arbitrage opportunities and revenues may be cannibalised.

There is strong evidence to suggest that additional capacity close to that currently agreed (NEMO, Eleclink, cap and floor window 1) will provide a net benefit to GB under many circumstances[47]. However, it is less clear whether significant additional interconnection beyond that will produce benefits to GB. The value of this interconnection will very much be asset and market specific and require more detailed consideration. Analysis focusing on GB suggests falling marginal benefits of certain additional interconnector capacity in at least in some market scenarios but more analysis would be beneficial. The majority of EU-wide studies would support much higher levels of interconnection, as these assess benefits over a wider geographical area.

Where interconnectors offer benefit to the wider European system rather than specifically to GB, this benefit could be shared appropriately so that GB can be a net beneficiary. Mechanisms for such transfers are considered further in ACER's proposed CBCA methodology.

Policy and regulatory barriers

From a commercial perspective, the increasing importance of less bankable arbitrage opportunities (especially volatility) could create a potential barrier for investment in interconnection, as a large infrastructure asset. This, together with current European regulation (allowing the European Commission to impose a cap on revenues for merchant interconnector projects) could make interconnectors high-risk projects with limited upside.

To address these issues, Ofgem has created the cap and floor regime, providing a level of downside security in exchange for giving up some upside potential. The strong uptake from cap and floor window 1 and the pipeline of additional proposed projects can be seen as, at least in part, representative of the removal of that barrier. There is no particular evidence from the review that additional material policy/regulatory barriers are restricting the ability of otherwise beneficial interconnectors from coming forward.

Competing Flexibility Options

Increasing intermittent generation resources and changing demand patterns will lead to greater and more complex needs for flexibility in wholesale electricity markets, due to increased forecast errors. Currently, most of that flexibility is provided by back-up generation, and, to a lesser extent, demand side response and interconnectors.

The literature reviewed agrees that interconnectors are capable of providing a range of flexibility to the GB system both directly through the transfer of energy but also indirectly by enabling access to other sources of flexible generation. While there will be some competition with interconnectors and other sources of flexibility, it appears likely that there will be room for a significant range of new entry because of the different scale of the various technologies, their focus on different sources of value and the scale of the increase of flexibility requirements.

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47 Although we note that evidence reviewed is not universally in favour, highlighting the need to carefully consider objective functions and market assumptions when drawing conclusions.

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ANNEX A – REFERENCES

A.1 Primary material referenced in report

Table 6 – Primary evidence base in order of appearance

No.	Title	Organisation	Publication Date	Weblink
1	'Presidency conclusions – Barcelona European Council'	European Council	March 2002	http://ec.europa.eu/invest-in-research/pdf/download_en/barcelona_european_council.pdf
2	'10-Year Network Development Plan 2014'	ENTSO-E	October 2014	https://www.entsoe.eu/major-projects/ten-year-network-development-plan/tyndp-2014/Documents/TYNDP%202014_FINAL.pdf
3	'ENTSO-E Guideline for Cost Benefit Analysis of grid Development Projects'	ENTSO-E	February 2015	https://www.entsoe.eu/Documents/SDC%20documents/TYNDP/ENTSO-E%20cost%20benefit%20analysis%20approved%20by%20the%20European%20Commission%20on%204%20February%202015.pdf
4	'Dash for Interconnection'	Aurora Energy Research	February 2016	https://auroraer.com/files/reports/Dash%20for%20interconnection%20-%20Aurora%20Energy%20Research%20-%20February%202016.pdf
5	'Benefits of Interconnectors to GB Transmission System'	National Grid	December 2014	https://www.ofgem.gov.uk/sites/default/files/docs/2015/03/nget_report_to_ofgem_-_qualitative_interconnector_benefits.pdf
6	'Connecting Wind Generation in Ireland to the Transmission Systems of Great Britain and Ireland'	EirGrid and National Grid	February 2013	http://www.interconnector.ie/site-files/library/EirGrid/Exporting%20Renewable%20Energy%20-%20Joint%20Study%20by%20EirGrid%20and%20National%20Grid%20%28Feb%202013%29.pdf
7	'Getting Interconnected'	Policy Exchange	June 2014	http://www.policyexchange.org.uk/images/publications/getting%20interconnected.pdf
8	'Recommendation on good practices for the treatment of the investment requests'	Agency for the Cooperation of Energy Regulators (ACER)	December 2015	http://www.acer.europa.eu/Official_documents/Acts_of_the_Agency/Recommendations/ACER%20Recommendation%2005-2015.pdf

9	'Near-term interconnector cost-benefit analysis	Pöyry for Ofgem	December 2014	https://www.ofgem.gov.uk/sites/default/files/docs/2014/12/791_ic_cba_independentreport_final.pdf
10	'Impact of EMR on interconnection'	Pöyry for DECC	December 2012	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/252744/Poyry_Report_on_Impact_of_CM_on_Interconnection.pdf
11	'Scoping towards potential harmonisation of electricity transmission tariff structures'	CEPA for ACER	August 2015	http://www.cepa.co.uk/publication-potential-harmonisation-of-electricity-transmission-tariff-structures?flBack=PB&selYear=2015
12	'Transmission tariff harmonisation supports competition'	Frontier Economics	2013	as quoted in [REF11]
13	'Impacts of further electricity interconnection on Great Britain'	Redpoint for DECC	November 2013	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/266307/DECC_Impacts_of_further_electricity_interconnection_for_GB_Redpoint_Report_Final.pdf
14	'Final Auction Results, T-4 Capacity Market Auction for 2019/20'	EMR Delivery Body	December 2015	https://www.emrdeliverybody.com/Capacity%20Markets%20Document%20Library/2015%20T-4%20Capacity%20Market%20Provisional%20Results.pdf
15	'Response to DECC consultation on Capacity Market supplementary design proposals and Transitional Arrangements'	Energy UK	November 2014	https://www.energy-uk.org.uk/publication.html?task=file.download&id=4958
16	'The Final Hurdle?: Security of supply, the Capacity Mechanism and the role of interconnectors'	University of Cambridge Energy Policy Research Group	September 2014	http://www.eprg.group.cam.ac.uk/wp-content/uploads/2014/09/1412-PDF.pdf
15	'Historical approaches to estimating interconnector de-rating factors'	Pöyry for DECC	February 2015	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/404337/Final_historical_derating_of_IC_poyry_report.pdf
18	'Confirmation of capacity auction parameters'	DECC	June 2015	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/439232/150629_SoS_NG_Confirmation_of_Capacity_Auction_Parameters.pdf

19	'Analysis of the correlation of stress periods in the electricity markets in GB and its interconnected systems'	Pöyry for Ofgem	March 2013	https://www.ofgem.gov.uk/sites/default/files/docs/2013/06/poyry---analysis-of-the-correlation-of-tight-periods-in-the-electricity-markets-in-gb-and-its-interconnected-systems_0.pdf
20	'The "Nemo" interconnector. Estimates of impact on TSO revenues, welfare and competition'	The Brattle Group	February 2011	https://www.ofgem.gov.uk/sites/default/files/docs/2013/12/2011_02_24_brattle_nemo_report_0.pdf
21	'Understanding the Balancing Challenge'	Imperial College London and NERA for DECC	August 2012	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48553/5767-understanding-the-balancing-challenge.pdf
22	'Achieving the 10% electricity interconnection target'	European Commission	February 2015	http://eur-lex.europa.eu/resource.html?uri=cellar:a5bfdc21-bdd7-11e4-bbe1-01aa75ed71a1.0003.01/DOC_1&format=PDF
23	'Value of Flexibility in a Decarbonised Grid and System Externalities of Low-Carbon Generation Technologies'	Imperial College London for the CCC	October 2015	https://documents.theccc.org.uk/wp-content/uploads/2015/10/CCC_Externalities_report_Imperial_Final_21Oct20151.pdf
24	'Dealing with Divergence'	Citi Group	January 2015	https://ir.citi.com/20AykGw9ptuHn0MbsxZVgmFyyppuQUUt3HVhTrcjz4ibR%2Bx79LajBxIyoHIoSDJ3S%2BWRSMg8WOc%3D
25	Crossing the Chasm. Solar Grid Parity in a Low Oil Price Era'	Deutsche Bank Markets Research	February 2015	https://www.db.com/cr/en/docs/solar_report_full_length.pdf

A.2 Additional background material reviewed but not directly referenced

Table 7 – Additional evidence base reviewed for this report

Title	Publication date	Organisation
Enabling a range of financing solutions under the cap and floor regime	December 2015	Ofgem
Decision to open a second cap and floor application window for electricity interconnectors in 2016	November 2015	Ofgem
Decision on the Initial Project Assessment of the Greenlink interconnector	September 2015	Ofgem
Cap and floor regime: Update on our Initial Project Assessment of the Greenlink interconnector	August 2015	Ofgem
Decision on the Initial Project Assessment of the FAB Link, IFA2 and Viking Link interconnectors	July 2015	Ofgem
Decision on the Initial Project Assessment of the NSN interconnector to Norway	March 2015	Ofgem
Announcement of de-rating methodology for interconnectors in the Capacity Market	February 2015	DECC
The benefits of integrating European electricity markets	February 2015	University of Cambridge Energy Policy Research Group
Addressing flexibility in energy system models	2015	European Commission Joint Research Centre, Institute for Energy and Transport
Decision on the cap and floor regime for GB-Belgium interconnector project NEMO – Briefing note	December 2014	CEPA
Decision on the cap and floor regime for the GB-Belgium interconnector project Nemo	December 2014	Ofgem
SO Submission to Cap and Floor	December 2014	National Grid
Electricity Interconnectors – The Crown Estate's proposed rent framework	October 2014	The Crown Estate
Participation of interconnected capacity in the GB capacity market	September 2014	Frontier Economics for DECC
Decision to roll out a cap and floor regime to near-term electricity interconnectors	August 2014	Ofgem
COMMISSION DECISION on the exemption of ElecLink Limited, C(2014) 5475	July 2014	European Commission
Strategic Development of North Sea Grid Infrastructure to Facilitate Least-Cost Decarbonisation	July 2014	Imperial College London and E3G

Integration of Renewable Energy in Europe	June 2014	Imperial College, NERA and DNV for the European Commission
The regulation of future electricity interconnection: Proposal to roll out a cap and floor regime to near-term projects, Consultation	May 2014	Ofgem
Cost assessment consultation for the proposed GB-Belgium interconnector, Nemo	April 2014	Ofgem
Infrastructure in a low-carbon energy system to 2030: Transmission and distribution	April 2014	Element Energy and Imperial College London for the CCC
Getting more connected	March 2014	National Grid
New electricity interconnection to GB – operation and revenues	February 2014	Baringa for DECC
Revealing the value of flexibility – How can flexible capability be rewarded in the electricity markets of the future?	February 2014	Pöyry
Interconnector participation in Capacity Remuneration Mechanisms	January 2014	Frontier Economics for Energy Norway
An approach to allow interconnector capacity to participate in the GB capacity mechanism	2014	National Grid and Statnett
Cap and floor regime for application to project NEMO: Impact Assessment, Consultation	December 2013	Ofgem
More interconnection: improving energy security and lowering bills	December 2013	DECC
Options for 2030 infrastructure targets Infrastructure and the EU 2030 climate and energy framework – discussion paper	December 2013	E3G
Consultancy support for the NEMO Interconnector – Cost assessment report	November 2013	British Power International for Ofgem and CREG
Impact on competition and social welfare of the proposed ElecLink interconnector between Great Britain and France	November 2013	London Economics for Ofgem and CRE
Application for EU exemption for a new interconnector between France and Great Britain	August 2013	Eleclink Limited
Regulation (EU) No 347/2013 on guidelines for trans-European energy infrastructure	April 2013	European Commission
Cap and Floor Regime for Regulated Electricity Interconnector Investment for application to project NEMO, Consultation	March 2013	Ofgem
Impact Assessment on European Electricity Balancing Market	March 2013	Mott MacDonald for DG ENER
Development of an Interconnector between the United Kingdom and Belgium	February 2013	Elia and National Grid Nemo Link Limited
Financeability study on the development of a regulatory regime for interconnector investment based on a cap and floor approach	February 2013	CEPA for Ofgem

Cost Benefit Analysis in the Context of the Energy Infrastructure Package	January 2013	THINK
Electricity System: Assessment of Future Challenges – Summary	August 2012	DECC
Electricity System: Assessment of Future Challenges – Annex	August 2012	DECC
Cross-border electricity interconnections for a well-functioning EU internal electricity market	June 2012	Oxford Institute for Energy Studies
Strategic Assessment of the Role and Value of Energy Storage Systems in the UK Low Carbon Energy Future	June 2012	Imperial College London for the Carbon Trust
Energy 2020 – A strategy for competitive, sustainable and secure energy, COM(2010) 639	November 2011	European Commission
Securing grids for a sustainable future – policy brief	October 2011	RAP
The challenges of intermittency in North West European power markets – extracted from a Pöyry Study	March 2011	Pöyry
Challenges for Nordic power – how to handle the renewable energy surplus	November 2010	Econ Pöyry and Thema
Options for 2030 infrastructure targets Infrastructure and the EU 2030 climate and energy framework	October 2010	Pöyry for the CCC
The economic welfare impacts of reserving interconnector capacity for trade in balancing products	September 2009	Frontier Economics for EBL

QUALITY AND DOCUMENT CONTROL

Quality control		Report's unique identifier: **2016/080**
Role	Name	Date
Author(s):	Benedikt Unger Stuart Murray	February 2016
Approved by:	Gareth Davies	February 2016
QC review by:	Matina Delacovias	February 2016

Document control			
Version no.	Unique id.	Principal changes	Date
v100	2016/XXX	Draft release	20/02/2016
v200	2016/XXX	Updated draft	23/02/2016
v300	2016/080	Final version	29/02/2016
v400	2016/080	Last updated final version	01/03/2016
v500	2016/080	Minor adjustment	02/03/2016

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