SO Submission to Cap and Floor

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1 Executive Summary

The aim of this paper is to provide an assessment of the range of services including ancillary services that five Interconnectors can facilitate and the potential financial benefits that the end consumer could see. It follows Note 1 which was submitted to Ofgem on 30 September 2014 and gives a qualitative overview of five technical areas that the assessed Interconnector would bring.

This is the published version that omits commercially sensitive data and analysis.

1.1 Scope of this paper

This paper has been produced at the request of Ofgem to provide monetised assessment of the range of services which Interconnectors can facilitate and the range of potential benefits to the end consumer. This analysis has been based on the ‘Gone Green’ scenarios described in Future Energy Scenarios (FES) for a single year (i.e. 2020), with little consideration, at this stage on potential generation developments in associated markets connected to the ‘remote’ end of the Interconnector. For the purpose of this analysis, the social economic welfare and capacity market benefits have not been considered.

This paper focuses on potential consumer benefits and does not consider how developers could extract value in delivering these benefits. It should also be recognised that further discussions are required with adjacent TSOs to ensure that neighbouring networks can support the provisions of services described.

1.2 Assessment areas

The technology used in the design of existing, and future Interconnector will allow for the provision of some of the new services which are required for future system operability.

Five Interconnector projects have been short listed for consideration under the Cap and Floor framework. These are:

- **Norway to England (NSN) Interconnector** – Blyth 400 kV – 1400 MW
- **Denmark to England (Viking Link) Interconnector** – Bicker Fen 400 kV – 1000 MW
- **Ireland to England (Greenlink) Interconnector with Ireland** – Pembroke 400 kV – 500 MW
- **France to England (IFA2)** – Chilling 400 kV – 1000 MW
- **France to Alderney England (FAB)** – Exeter 400 kV – 1400MW

In undertaking this analysis it was assumed that both ElecLink (1000MW France to England Interconnector) and Nemo (1000MW Belgium to England Interconnector) had been commissioned. The assessments cover the five Interconnectors in 14 combinations for monetary benefits in the following areas:

- Frequency response
- Black start
- Reactive response
- Boundary capability delivered (displaced investment)
- Constraint management (operational cost implications)

1.3 Confidentiality

The assessments in this report were based on price sensitive information. The release of this information could compromise the ability of the System Operator to obtain these services at the most economic rates. This published version omits commercially sensitive data and analysis.

1.4 Outputs

It should be noted that the benefits and costs identified in this report are those which are seen the end consumer and are based on costs which may have been incurred based on current practices. We would envisage that the utilisation of HVDC Interconnectors to provide the ancillary services, in a competitive environment, would significantly reduce these costs.

Table 1 provides an overview of the potential annual monetised benefits. In particular the table presents, a range of annual financial benefits associated with potential services delivered through the 14 Interconnector combinations. Of the 14 combinations, five are each Interconnector alone with the remaining nine being combinations that were agreed with the Regulator.

Benefits such as frequency response are system wide while others such as reactive response are localised. Nevertheless where a local benefit is identified, the financial benefit is to the consumer nationwide in avoided expenditure on reactive compensation plant.

Table 2 provides the forecast for additional cost of constraints resulting from the Interconnectors and considered combinations. Like the analysis presented in Table 1, Table 2 presents a range of operational cost implications associated with the 14 combinations.

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1.5 Complete Overview tables of the potential benefits and costs (£m)

Overall annual value of services (£m)	NSN only		Viking Link only		Greenlink only		IFA2 only		FAB only		All Interconnector		All except Greenlink		All except NSN		All except Viking Link		IFA2 and FAB		IFA2, FAB & Greenlink		IFA2, FAB & NSN		IFA2, FAB & Viking Link		NSN & Viking Link	
	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit
Frequency response	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Black start	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Reactive response	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Boundary capability delivered *(annualised displaced investment)*	0	2.3	0	0	0	0	0	2.6	0	0.4	0	4.9	0	4.9	0	2.6	0	4.9	0	2.6	0	2.6	0	4.9	0	2.6	0	2.3
Total	**31.4**	**62.4**	**23.4**	**46.1**	**0**	**0**	**22.2**	**48**	**32.4**	**63.5**	**116.5**	**155.7**	**115.5**	**155.7**	**82.1**	**145.3**	**90.1**	**148.6**	**56.6**	**113.2**	**56.6**	**113.2**	**90.1**	**148.6**	**81.1**	**145.3**	**56.8**	**112.6**

Table 1: Complete overview of the valuation (2014 prices)

Annual Operational Costs (£m)	NSN only		Viking Link only		Greenlink only		IFA2 only		FAB only		All Interconnector		All except Greenlink		All except NSN		All except Viking Link		IFA2 and FAB		IFA2, FAB & Greenlink		IFA2, FAB & NSN		IFA2, FAB & Viking Link		NSN & Viking Link	
	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit
Constraint management *(operational cost implications)*	-42	5	-10	4	-27	-9	-4	8	-6	12	-56	21	-41	28	-34	11	-45	20	-10	11	-24	8	-40	24	-29	9	-34	14

Table 2: Constraint management costs (in 2014 prices)

Commentary on Table 1

The ancillary Frequency Response service identifies the value of Interconnector to provide on a national geographical scale. Increasing numbers of interconnectors reduces the ability for each one to maximise their potential benefit.

The Reactive Response results represent the benefits that interconnectors bring locally to the area of connection considering that reactive support service is a locally related phenomenon. The results demonstrate the benefits in (£m) which interconnectors brings to the transmission network in comparison to the benefits from reactive support investment in form of shunt reactor and STATCOM. A shunt reactor absorbs reactive power and is used in reactive power compensation for voltage control. A STATCOM can both supply and absorb reactive power under a control system that can respond to system conditions.

However, if the interconnectors enter the reactive power market then the benefits of the interconnector will depend on the price of reactive response in reactive market.

As was already mentioned the reactive support service is a local oriented phenomena therefore the combination with other interconnectors will not bring additional benefits to the area where the interconnector is connected. However, the results in the table related to column related to interconnector combinations present the sum of the benefit of different interconnector to the reactive response (e.g. NSN and IFA2 and FAB, benefits to reactive power support is sum of each benefit separately). When all Interconnectors are studied in combination, the total value available to all the Interconnectors ranges between **£m** and **£m**.

For Black Start services Interconnectors with the correct technical capabilities could each provide a benefit from circa £m to just over £m per year.

Due to the inherent nature of HVDC VSC to provide voltage support, some of the Interconnector and their associated combinations have the potential to increase the transfer capability across certain boundaries. Through doing so, they could defer alternative investments which would be required on these boundaries; the cost of this potential deferred investment is outlined in the table. It is calculated based on NGET's incremental wider works (IWW) allowance for each of the impacted boundaries.

Table 2 summarises the forecast of additional operational management costs for the GB transmission system for the spot year 2020 against the Gone Green generation and demand background. A negative value denotes an increase in constraints while positive denotes a reduction in the constraint costs. The analysis adopts National Grid's envisaged view of the counterfactual network state by 2020, which is considered to be sufficient to meet the power flow requirements of generation forecast by 2020 in the Gone Green scenario.

The results summarised in the table suggest that constraint costs would increase for most combinations considered. This is not least because the network lacks additional capacity which may require further reinforcements if any of the Interconnectors or combinations considered through this cap and floor assessment were to materialise. Hence, the increase in constraint costs do not represent lack of benefits resulting from Interconnectors; rather it represents a lack of network capacity. However, as represented by the upper limits of the operational cost analysis, a change in cost of constraining Interconnectors would result in a reduction in constraint costs for all combinations considered, excluding the Greenlink only scenario.

Key Findings

Our initial assessments do identify monetary benefits from services that Interconnectors could provide which in turn will benefit the GB consumer. However, it should also be noted, that whilst some of the benefits identified in this paper have low monitory value, they would play a key role in operating an increasing complex network.

There are largest benefits to be gained from the provision of Frequency Response. Other benefits such as for black start provision and reactive response are much less.

The analysis also demonstrates that with the right technology Interconnectors could result in additional boundary capability, which could provide further monetised benefits in terms of displaced investment. Furthermore, a change in cost of constraining Interconnectors could result in a reduction of operational costs of the network.

2 Introduction

This paper follows one submitted to Ofgem on 30 September 2014 which gave an overview of the range of services that Interconnector could provide. That paper gave an overview of the technology available and for the services, a definition of the service together with commentaries on the future challenges to system operation due to the changing nature of generation, particularly in the context of increasing renewable generation, and how Interconnector could provide benefits in these areas. The first paper did not monetise the benefits - that is the objective of this paper.

This paper is written with a chapter per Interconnector with each chapter being designed to be free-standing. Following a summary introduction and tabulated summary of benefits, the chapter covers the full set of topic areas for the Interconnector concerned. Where there are benefits affected by combinations of Interconnector, these are described by the table with a commentary in the main text.

This assessments has been requested by Ofgem as part of their wider analysis of the Interconnector's benefits, the report quantifies benefits but does not produce conclusions. Clear outcomes for each Interconnector depend on this wider input. It should also noted that this analysis is based on limited detailed system studies and if this type of analysis is required for further evaluation it will be necessary to significantly further develop the methodology and techniques which are utilised in the preparation of this analysis.

The 14 Interconnector combinations were agreed with Ofgem[1]. The study work was predominately based on the 2020 Gone Green scenario from the Future Energy Scenarios (FES) which National Grid publishes each year.

The technology choices made by the Developers in the design of existing and future Interconnector may allow for the provision of some of the services which are required for future system operability.

HVDC links are based on either Current Source Converter (CSC), or Voltage Source Converter (VSC) technology. The latter (being a more recent technology) is also capable of operating within weaker systems, and is less susceptible to disturbances. VSC technology is more capable of facilitating the delivery of ancillary services too. These services include fast power ramp up/ramp down, voltage control, black start, etc. to be provided at a small incremental cost, as they are the inherent capabilities of the voltage source HVDC technology.

Frequency Response

The real-time difference between system demand and total generation, results in continuous changes to the system frequency. The SO must ensure that sufficient response from various sources such as generation, demand, or Interconnector is held to manage the system frequency. In the future, with the changes expected in the Energy mix, such as increasing renewables and larger nuclear generation capacity, new measures to control the

[1] whereas the strict mathematical combination would have been 120 in addition to a further option of no Interconnector

system frequency will be required. Continuation of existing policies for managing frequency response would result in the operating costs increasing from around £60m to circa £200m-£250m per annum. Interconnectors VSC have the ability to rapidly change their power output across their full operating range, thus making them a very suitable option for managing the system frequency in the future.

Black Start Capability

The costs for procuring the Black Start service are generally forecast to increase towards 2020 as the number of new plant required for contract increases against the backdrop of expiring contracts and closing plant. The contracting strategy for Black Start is an evolving process which is continually reviewed. It has been identified that interconnectors can provide Black Start capability if they are of HVDC VSC design and sufficient system strength exists behind the interconnected system to provide support. Our analysis focused on identifying the impact and associated benefits that the five 'Cap & Floor' interconnectors could have on Black Start economics in 2020 if contracted with. It demonstrated that interconnectors if contracted with could provide net economic savings on the overall Black Start procuring costs

Reactive Power Response

The reactive demand seen by the Transmission system is falling. Closure and lower utilisation of conventional power plants on the system, reduces the potential reactive response available at optimum locations, reducing system capability to control voltage, and may result in the need for investment in additional reactive compensation. Interconnectors are designed with inherent reactive compensation which can be utilised to generate or absorb reactive power as required without the need for any additional equipment. Interconnectors can also provide additional benefits of dynamic voltage control and system stability.

However, unlike system frequency, which is consistent across the network, voltage is a local issue which is uniquely related to the prevailing real and reactive power supply and demand in a local area. The SO must manage voltage levels on a local level, and without the appropriate injections of reactive power at the correct locations, the voltage profile of the transmission system will exceed statutory limits, therefore the benefits an Interconnector can provide is dependent on the location which Interconnector is connected to.

Boundary Capability

The ability of a transmission network, in key areas, to transfer energy from generation to supply can be described in terms of boundary capability. Each boundary in the transmission network is required to securely enable the economic and secured level of power transfer. Future changes in generation and demand will change the nature of power flows on the transmission system, potentially leading to transmission constraints across some boundaries. Depending on the design of the control system, an Interconnector may facilitate either a reduction of transmission investment and/or increase some boundary capabilities.

Constraint Management

When a network constraint occurs, the SO takes actions in the market to increase and decrease the amount of electricity at different locations on the network to ensure network boundary limitations are not exceeded. Interconnectors facilitate the SO entering into a contractual agreement with the corresponding SO in the interconnected market to allow the transfer of energy from one SO to the other across either solving a system constraint or to aid the balancing of the system. This could reduce operating costs particularly during times when there is spare capacity on the Interconnector. This service would be convertor technology neutral.

It is worth noting that the current analysis is based on historically observed values for constraining Interconnectors through week ahead trading and SO actions. As the number of Interconnectors increase, competition may reduce the cost of constraining Interconnectors. Equally, the implementation of European codes could lead to similar affects. Hence, increased interconnectivity could lead to a reduction in operational costs of the GB network.

Figure 1 below shows the GB transmission network with 5 new Interconnector which benefits will be assessed in this document.

GB Transmission Network with Interconnectors

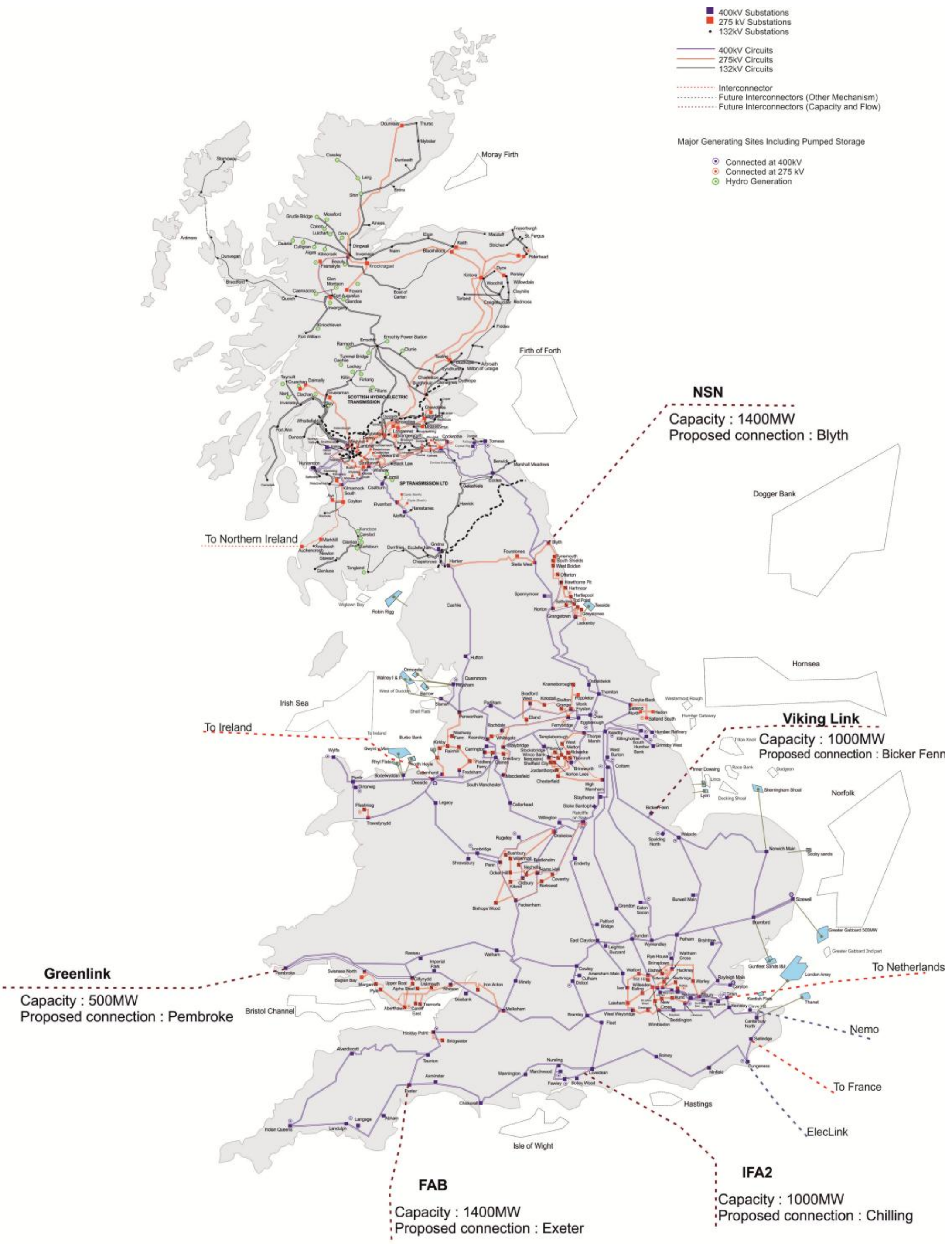

Figure 1: GB transmission System with Interconnectors connected on the map

All Interconnector cable routes shown on this map are indicative only

Dependency of benefits to the European electricity market

There is currently a great diversity of arrangements for ancillary services throughout Europe. Common rules for cross border exchanges of such services are included within the future Network Code on Electricity Balancing.

The Network Code on Electricity Balancing shall set all necessary features to facilitate the development of cross-border exchange of balancing energy, and encourage that these are made possible on every border, in the limits defined by the Network Code on Load Frequency Control and Reserve concerning procurement of Ancillary Services. Reservation of cross-border capacity for the purpose of balancing energy is only allowed for cases where TSOs can demonstrate that such reservations would provide socio-economic efficiencies.

The number of benefits associated with an Interconnector is dependent on the market environment and physical characteristics of the system the Interconnector is connected to. For example, the provision of frequency response at one end may have an impact on the other system and as such may limit the capability and benefit associated with the Interconnector. The technical capability of an Interconnector to deliver ancillary services, within various timescales should be carefully evaluated, considering both the technical characteristics of the Interconnector and the technical definition of the products in the market.

2.1 Methodology Overview

Each of the services assessment areas required the development of a methodology. Below is a summary of those methodologies while a full account is in the appendices of this report.

2.2 Determination of Range of Potential Power Flows across the Interconnector.

To determine the potential for a HVDC Interconnector to provide ancillary services a few of the range of potential transfers on any given Interconnector is required (for example a partly loaded Interconnector as greater capability to provide frequency response).

National Grid used its in house tool used to prepare long term forecast of constraints costs, namely ELSI (Electricity Scenario Illustrator). National Grid has undertaken this utilise the Future Energy Scenarios 2014 and focus on Gone Green scenario (year 2020 as a priority). By utilising ELSI, with a constraint free transmission system, central price forecast for GB can be determined. We have then the extended the capability of ELSI to model different member states as single nodes, with network restriction between a members state and GB network represented by the Interconnector capability being modelled.

In determining the range of power flows across the Interconnector, one of the most significant assumptions is energy price forecasts for different European member states. We have developed energy price forecasts for 2020 for various member states[2], including seasonal variability and fluctuations within different period of the day. The central price forecasts are summarised in the figure 2 below. As the analysis for the GB network is based on Gone Green scenario, it is worth noting that these price forecasts represent a similar vision for considered European markets.

As the outputs of this analysis are sensitive to price assumptions for European member states, due considerations have been given to establish implications of increase or reduction in European prices. Details regarding these price sensitivities are presented in the Appendix C.

[2] It is recognised that a limitation of this analysis is that whilst the GB energy prices are influenced by level of Interconnector transfers, the European Energy prices remain fixed for periods and seasons.

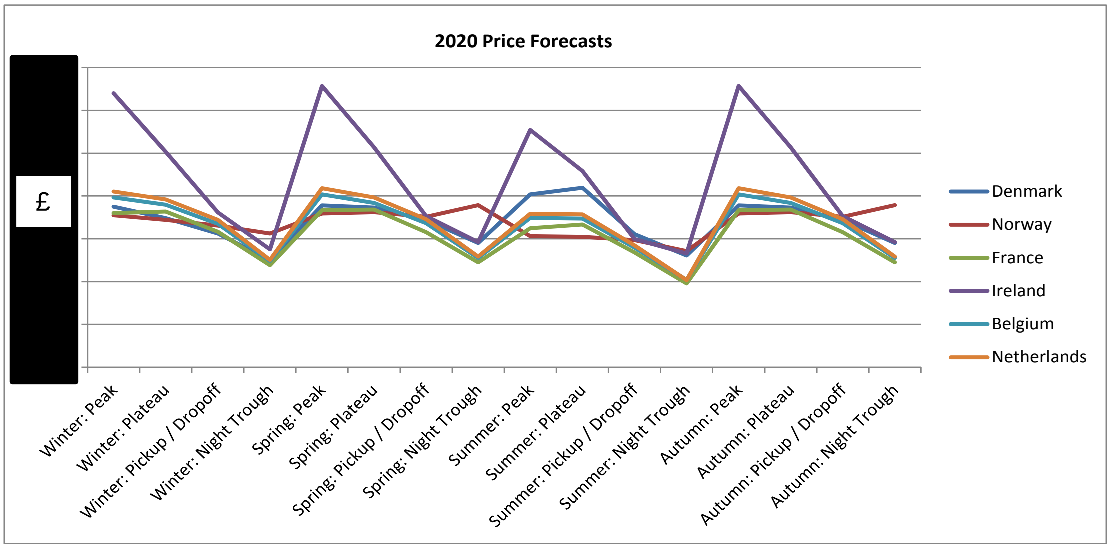

Figure 2: 2020 central price forecasts for different European energy markets (in £s per MWh)

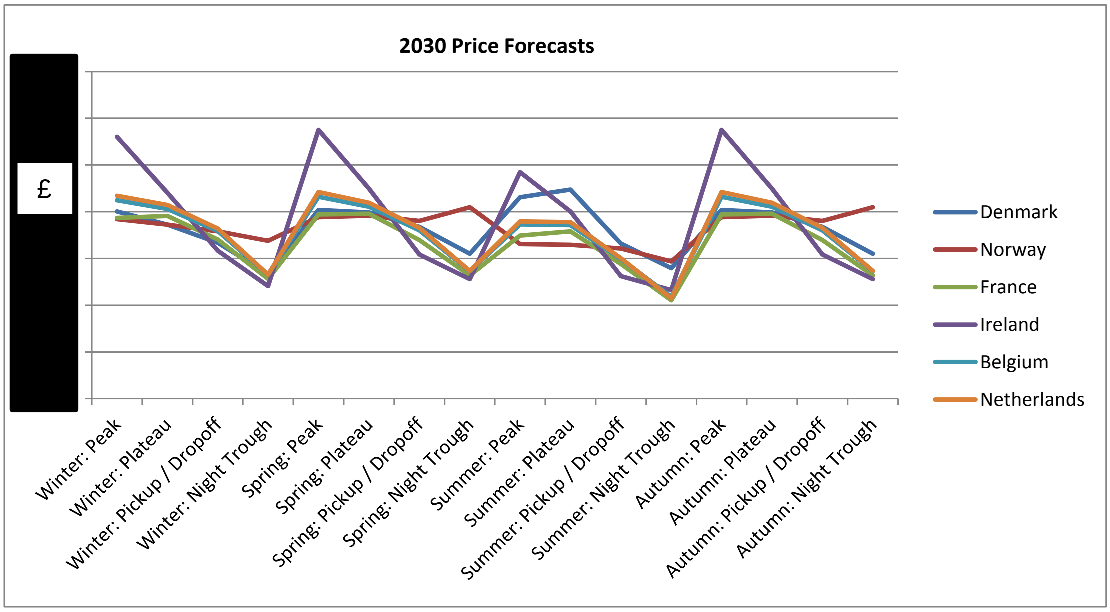

Figure 3: 2030 central price forecasts for different European energy markets (in £s per MWh)

Based on the price forecasts (including price sensitivities), in 2020, the load factors for the new French, Danish and Norwegian Interconnector remains very high and varies marginally across all combinations considered. However, amongst these new Interconnector with markets in mainland Europe, the NSN Interconnector is forecasted to have the greatest level of exports, as a proportion of its capacity, from GB. In comparison the new Greenlink Interconnector achieves a lower load factor. Furthermore, exports from GB as a proportion of the new Interconnector's capacity are forecasted to be the greatest on the Greenlink link. It is also worth noting that as GB's interconnectivity with mainland Europe increases, exports from GB, particularly to Ireland expand.

Markets/ Combinations	Flow direction	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Intercon France	GB import	89-91%	89-91%				89-90%	88-89%	89-91%	89-90%	89-90%	89-91%	88-89%	88-90%	
Intercon France	GB export	0%	0%				0%	0%	0%	0%	0%	0%	0%	0%	
Intercon Denmark	GB import				88-89%		83-85%	83-84%	83-85%					83-84%	87-89%
Intercon Denmark	GB export				1%		1%	1%	1-2%					1-2%	1%
Intercon Ireland	GB import			41-70%			21-47%		22-52%	27-47%		28-64%			
Intercon Ireland	GB export			3-14%			14-24%		9-21%	10-21%		7-21%			
Intercon Norway	GB import					85-87%	78-80%	79-81%		81-82%			81-83%		83-86%
Intercon Norway	GB export					4%	7-9%	6-8%		6-7%			5-7%		4-5%

Table 3: 2020 forecast load factors for new Interconnector across all considered combinations (central price forecast and price sensitivities)

Based on the price forecasts (including price sensitivities), in 2030, the load factors for the new French, Danish and Norwegian Interconnector remains high, but with more two-way trading, and varies marginally across all combinations considered. However, amongst these new Interconnector with markets in mainland Europe, the NSN Interconnector still has the greatest level of utilisation, as a proportion of its capacity, from GB, but again, with significant two-way trading. In comparison the Greenlink Interconnector is forecast to achieve a slightly lower load factor across a range of price scenarios. It is also worth noting that as GB's interconnectivity with mainland Europe increase, imports from Ireland decrease.

Markets/ Combinations	Flow direction	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Intercon France	GB import	52-54%	52-54%				47-51%	48-52%	49-52%	47-51%	49-52%	49-52%	47-51%	50-53%	
Intercon France	GB export	18-22%	17-22%				9-13%	11-14%	12-16%	12-16%	16-21%	15-19%	14-18%	13-17%	
Intercon Denmark	GB import				45-49%		35-40%	36-41%	37-40%					38-41%	45-47%
Intercon Denmark	GB export				26-31%		25-31%	26-32%	26-31%					26-32%	25-30%
Intercon Ireland	GB import			46-49%			22-26%		24-30%	25-31%		28-35%			
Intercon Ireland	GB export			26-31%			30-33%		29-33%	30-34%		29-34%			
Intercon Norway	GB import					46-52%	42-46%	43-47%		43-47%			43-48%		45-51%
Intercon Norway	GB export					28-32%	29-33%	28-33%		28-33%			28-33%		27-32%

Table 4: 2030 forecast load factors for new Interconnector across all considered combinations (central price forecast and price sensitivities)

Key:

1. IFA2 Only	5. NSN Only	9. All projects minus Viking Link	13. Both French and Viking Link only
2. FAB Only	6. All five projects together	10. Both French Interconnectors only	14. Both Viking Link and NSN only
3. Greenlink Only	7. All projects minus Greenlink	11. Both French and Greenlink only	
4. Viking Link Only	8. All projects minus NSN	12. Both French and NSN only	

The 2020 and 2030 price assumptions for interconnected member states and projected load factors influence our analysis for impacts associated with ancillary services. Further details can be found in Appendix A.

2.2.1 Frequency response

In order to assess the value of future GB Interconnector to provide frequency response, we have performed extensive studies[3] in order to:

a) Examine the impact of FES on system inertia and the rate of change of frequency.
b) Determine the volume, and the respective cost of frequency response required in the future;
c) Assess the volume of current response offset by provision of a "faster" response.
d) Determine how HVDC Interconnectors can provide the fast response and the value of the potential future fast response market for the Interconnectors.

The HVDC Interconnector's capability in providing fast response is dependent on various factors; notably:

- Response Capability: The amount of response an Interconnector combination can provide is referred to as a percentage of its total capacity. The two cases studied are for 10% and 5% response capability**.**
- Availability: The amount of time an Interconnector is available. Due to the probability of a fault decreasing the more Interconnectors are used in a combination, the following availabilities for the "fast response rate required" have been assumed:
  - For the case of one interconnector, the level of fast response rate is assumed to be available for 95% of the time. 95% technical availability (not frequency response availability) is based on the assumptions adopted for market modelling;
  - For the case of two interconnectors in a combination, the level of fast response rate is assumed to be available for 99% of the time; and
  - When three or more interconnectors in a combination are studied, the level of fast response rate is assumed to be available for 100% of the time.
- Load flow regime: The forecasted load flow on a Interconnector impacts upon its ability to provide Fast Response services; either Primary of High. Primary response is needed when there is a generation loss, and the system frequency decreases. High response is needed when there is a demand loss and system frequency increases. Each service usability is outline below:
  - When an Interconnector is importing to GB, only High Response can be utilised.

[3] National Grid's System Operability Framework (SOF) – September 2014 – Available: http://www2.nationalgrid.com/UK/Industry-information/Future-of-Energy/System-Operability-Framework/

- When an Interconnector is exporting from GB, only Primary Response can be utilised.
- When an Interconnector is on Float (Neither importing nor exporting), both services can be utilised.

For full details of the methodology, and the application of this methodology, please refer to appendix A.

In this report, the value of providing fast frequency response by the Interconnector under study is presented. In doing so, each Interconnector is studied individually, as well as when other Interconnectors are present.

2.2.2 Reactive Response

The methodology to quantify benefits from reactive support from the Interconnector was based on network power system studies with reduced power demand which is known as a network with summer minimum load. The network with minimum load has a tendency for higher system voltages during the summer months. The lower demand means fewer generators will operate and those that do run could do so at a reduced power factor output. The three main steps in the reactive response methodology are: Forecast Cost of Reactive Reserve in 2020, system studies to assess the need for reactive support from the Interconnector and economic analysis to quantify the benefits from the Interconnector in comparison to investment in shunt reactor and STATCOM.

2.2.3 Constraint management

For constraint management, National Grid used its in house tool used to prepare long term forecast of constraints costs, namely ELSI. Analysis undertaken as part of this round of Cap and Floor consultation will utilise the Future Energy Scenarios 2014 and focus on Gone Green scenario (year 2020 as a priority).

Firstly, unconstrained flows are modelled between GB and the interconnected member states when no network limitation exists. The outputs from these results represent the true market driven flows based on the price arbitrage between the two markets. Secondly a base case constrained flow is established, this consists of the forecast constraint costs in the year 2020 if none of the proposed cap and floor projects materialise. At this stage it is worth noting that the capabilities will be set as ETYS 2014 Year 7 (2020/21). This base case sets the counterfactual for valuing the benefits of the agreed combinations in terms of constraint management. Constrained runs were then undertaken for each of the fourteen Interconnector combinations.

In order to forecast the 'total' operational cost implication of an Interconnector, the flows for constrained run need to be reconciled with the unconstrained run. Each MWh of reconciliation between constrained and unconstrained runs will be valued at a respective benchmark value associated with the interconnector[4]. Furthermore, the effects of increased or reduced cost constraining interconnectors have also been appraised as part of this assessment.

The outputs of annual operational costs for each combination will be subtracted from the counterfactual constraint forecast. The impact estimates are presented in terms of present value (2014/15 prices). In the analysis negative values denote an increase in operational costs whereas positive values denote a reduction in operational costs.

[4] The benchmark values have been developed from relevant price assumptions for both SO-SO actions and week ahead trading price. Please note that both set of assumptions as well as the derived averages (for reconciliation costs) are based on direction of flow and the envisaged interconnected market.

3 Analysis of NSN Interconnector to Norway

3.1 Introduction

The proposed 1400 MW Interconnector would connect to the GB transmission system at Blyth in the North East of England.

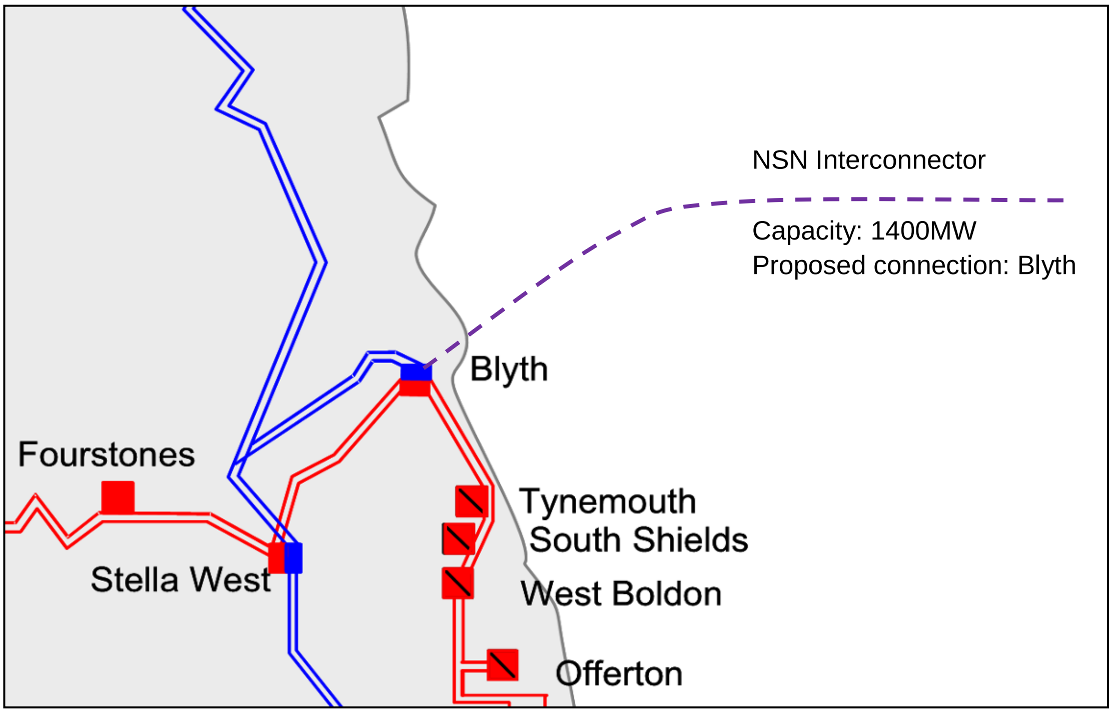

Figure 6: Proposed NSN Interconnector connection to existing GB Transmission System

The Interconnector cable route shown on this map is indicative only

The monetised benefits for the services which the NSN Interconnector could provide have been considered for the combinations identified below:

- NSN only
- All Interconnector
- NSN and others apart from Greenlink
- NSN and others apart from Viking Link
- NSN and French only
- NSN and Viking Link only

3.1.1 Frequency response

The changes expected in the generation mix will increase the volume of required frequency response by 2020. An alternative to increase the volume of frequency response is to provide faster response via HVDC Interconnectors.

The potential benefit to the end consumer if NSN was to provide fast response when considered in isolation (that is the only HVDC Interconnector providing this service) is between £m and £m per annum, assuming that the service is limited to either **5%** or **10%** of the capacity of the link being made available to provide fast response respectively (capacity being restricted to this value to minimise both the impact on potential trading opportunities and impact on external systems providing this service).

When all Interconnectors (except Greenlink) are assumed to be in service, the potential benefit to the end consumer is a reduction in costs to provide this service in the range £m and £m but the NSN contribution to the saving remains in the region £m to £m per annum.

In other combinations:

Assuming both French and NSN are available to provide this service, the benefit to the end consumer is between £m and £m. The combination of Viking Link and NSN Interconnector returns an overall benefit between £m and £m. For both of these combinations NSN can only provide a maximum of £m of benefit.

Value to the Interconnector:

The values presented here for the interconnectors are the "savings" resulted for the end-consumer and not the potential earning for the interconnector(s). Factors such as increase in competition in the provision of this service (for example multiple HVDC Interconnectors competing to provide the service) and the introduction of new services (for example from DSR and/or renewable generation) is expected to limit the potential value that interconnector(s) could extract in providing this service to below the values identified in this report.

3.1.2 Reactive response

The results for analysis undertaken in examining the potential benefits that the NSN interconnector can provide in respect to provision of voltage support is in the range of £m to £m per annum, when compared to investment of reactive response in form of shunt reactor and STATCOM respectively.

The results were obtained based on calculations that North East Area required 500MVAr reactive compensation from the interconnector to keep the voltage within the operational limits. This avoided capital costs required for investment for a shunt reactor and STATCOM are £14.1m[5] and £24m respectively.

However, if the NSN interconnector enters the reactive market then the reactive response benefits will depend on the market price for the reactive response service.

Reactive support is a local oriented phenomenon therefore the NSN in combination with other interconnectors will not change the benefits identified.

3.1.3 Boundary Capability

For planning purposes, the transmission network in England and Wales is divided by a number of boundaries. The maximum power transfer across the boundaries identifies the boundary capability. In considering the NSN Interconnector, the key boundaries are B6 and B7. To obtain the benefits identified below, the use of VSC technology is required (CSC will not provide the increase in boundary capability).

3.1.3.1 Boundary B6

Studies suggest that the contribution from HVDC to NSN would increase the voltage collapse limit by **50MW**. As the NSN connects on the eastern side of B6, the voltage support from the Interconnector can be seen mainly on the eastern side. By active power modulation (of NSN) damping the rotor angle oscillations is achieved and hence increase boundary capability of **300MW** can be delivered. Therefore, the combined maximum incremental capability including voltage collapse and rotary angle oscillations (with a further MSC at Harker at a cost of £5m) delivered by NSN on boundary B6 is estimated at **350MW**.

3.1.3.2 Boundary B7

NSN HVDC can deliver incremental boundary capability of **160MW** to the B7 boundary by relieving the under-voltage[6] that occurs in the base case at Spennymoor 400kV.

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[5] The cost of a 200 MVAr Shunt Reactor is £4.7m. In the case of the North East we need 500 MVAr reactive response therefore the cost for shunt reactor is £14.1 = 3 x £4.7

[6] Voltages below the planning limits

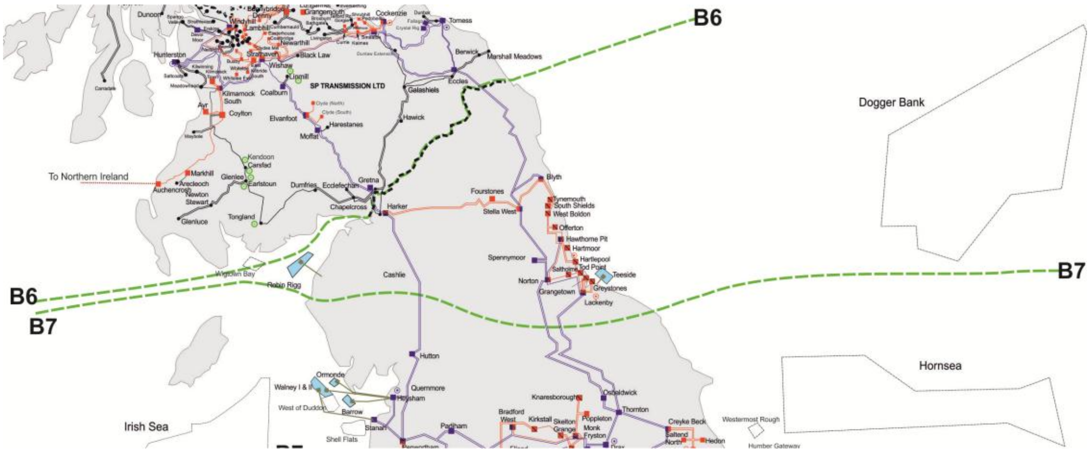


Figure 9: GB Boundaries affected by NSN

3.1.3.3 Displaced Capital Investment

From 2020, NSN could provide additional voltage support which would result in a boundary capability increase of 160 MW on B7 and 350 MW on B6. This additional capability has the potential to displace future investment across these boundaries. The cost of the displaced investment is derived from National Grid's incremental wider works allowance. The displaced investment due to NSN and all other studied combinations which include NSN is shown in the table below[7].

Interconnector combination	NSN Only	All Interconnectors	All except Greenlink	All except Viking Link	IFA2, FAB & NSN	NSN & Viking Link
Potential total investment displaced	Up to £43.3 m	Up to £91.7 m	Up to £91.7 m	Up to £91.7 m	Up to £91.7 m	Up to £43.3 m
Annualised potential displaced investment[8] cost	Up to £2.3 m	Up to £4.9 m	Up to £4.9 m	Up to £4.9 m	Up to £4.9 m	Up to £2.3 m

Table 5: Displaced Investment Benefit of NSN Interconnector

[7] For NSN and all NSN combinations, the investment displaced includes the additional cost of an MSC (~£5m) which is required for NSN to provide maximum boundary capability increase.

[8] Annualised capital costs including cost of finance based on an assumed 40 year asset life.

3.1.4 Constraint Management

This section outlines the annual operational cost implications of NSN and associated combinations for the GB network in 2020. The analysis is based on 2020 forecast of GB network, which includes reinforcements for key boundaries[9]. The analysis results, which are summarised in the table below, have been presented in 2014 price base.

Interconnector combinations	NSN Only	All Interconnectors	All except Greenlink	All except Viking Link	IFA2, FAB & NSN	NSN & Viking Link
Central Case	-£17 m	-£14 m	-£1 m	-£9 m	-£1 m	-£12 m
Upper Limit	£5 m	£21 m	£28 m	£20 m	£24 m	£14 m
Lower Limit	-£42 m	-£56 m	-£41 m	-£45 m	-£40 m	-£34 m

Table 6: Annual Operational Cost Implication of NSN Interconnector

As outlined in the methodology in Appendix C, the operational cost implications of a certain interconnector or combinations are a function of energy prices in interconnected markets across Europe and the modelled system marginal price for GB in 2020. The analysis has been performed for a range of price forecasts for European markets. Furthermore, the analysis considers a price range for constraining interconnector flow, which includes week-ahead trades and SO to SO actions. The central case includes base market prices and base interconnector constraint costs. The upper and lower limits include sensitivities on these prices and costs.

The analysis demonstrates that the addition of NSN only could increase operational costs of the GB network in 2020 by up to £42m per annum. However, a change in price assumptions (including European market prices and constraint cost for interconnectors) could result in a reduction in operational costs of up to £5m per annum. This reduction in operational costs of GB network is considered as a benefit of the interconnector. The analysis for NSN based interconnector combinations suggests that the operational costs implications could range from an increase of approximately £56m per annum to a reduction of some £28m per annum.

3.2 Summary of results

Table 7 summarises the monetised benefits for the services areas for the NSN Interconnector and five additional combinations. Table 8 presents the annual operational cost implications for NSN and the same combinations.

The tables present ranges of annual values in £m (2014 prices) for each service and operational cost.

[9] The analysis undertaken for NSN and any related combinations assume additional reinforcement of B7a. Details of this reinforcement, such as capital cost, need to be developed further.

£m	NSN only		All Interconnector		NSN and others apart from Greenlink		NSN and others apart from Viking Link		NSN with French only		NSN with Viking Link only	
	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit
Frequency response	X	X	X	X	X	X	X	X	X	X	X	X
Black start	X	X	X	X	X	X	X	X	X	X	X	X
Reactive response	X	X	X	X	X	X	X	X	X	X	X	X
Boundary capability delivered (Annualised displaced investment)	0	2.3	0	4.9	0	4.9	0	4.9	0	4.9	0	2.3
Total	**31.4**	**62.4**	**116.5**	**155.7**	**115.5**	**155.7**	**90.1**	**148.6**	**90.1**	**148.6**	**56.8**	**112.6**

Table 7: Value of NSN Interconnector and associated Interconnector combinations

£m	NSN only		All Interconnector		NSN and others apart from Greenlink		NSN and others apart from Viking Link		NSN with French only		NSN with Viking Link only	
	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit
Constraint management (Annual operational cost implications)	**-42**	**5**	**-56**	**21**	**-41**	**28**	**-45**	**20**	**-40**	**24**	**-34**	**14**

Table 8: Annual Operational Cost Implications of NSN Interconnector and associated Interconnector combinations

4 Analysis of Viking Link Interconnector to Denmark

4.1 Introduction

The proposed 1000MW Interconnector would connect to the GB transmission system at Bicker Fen in Lincolnshire in the east of England.

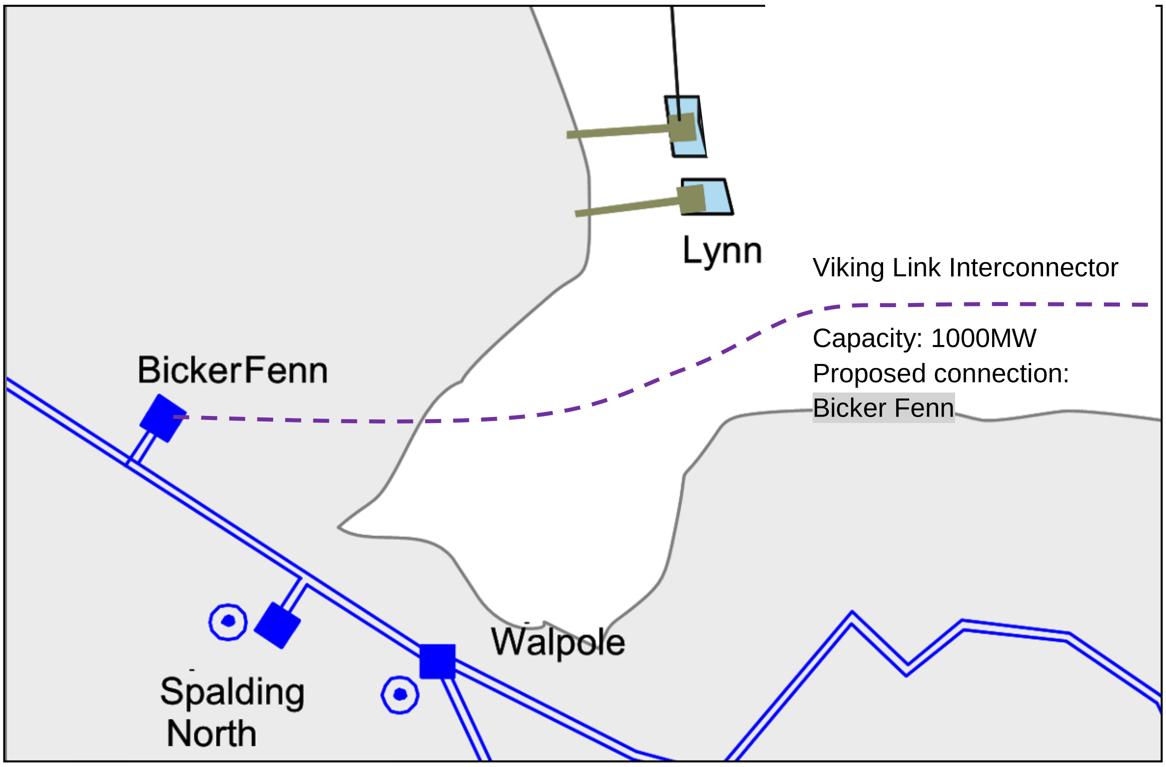


Figure 10: Proposed Viking Link Interconnector connection to existing GB Transmission System

The Interconnector cable route shown on this map is indicative only

The monetised benefits for the services which the Viking Link Interconnector could provide have been considered for the combinations identified below:

- Viking Link only
- All Interconnector
- Viking Link and others apart from Greenlink
- Viking Link and others apart from NSN
- Viking Link and French only
- NSN and Viking Link only

4.1.1 Frequency response

The changes expected in the generation mix will increase the volume of required frequency response by 2020. An alternative to increase the volume of frequency response is to provide faster response via HVDC Interconnectors.

The potential benefit to the end consumer if Viking Link was to provide fast response when considered in isolation (that is the only HVDC Interconnector providing this service) is between £m and £m per annum, assuming that the service is limited to either **5%** or **10%** of the capacity of the link being made available to provide fast response respectively (capacity being restricted to this value to minimise both the impact on potential trading opportunities and impact on external systems providing this service).

When all Interconnectors (except Greenlink) are assumed to be in service, the potential benefit to the end consumer is a reduction in costs to provide this service in the range £m and £m but the Viking Link contribution to the saving remains in the region £m to £m per annum.

In other combinations:

Assuming both French and Viking Link are available to provide this service, the benefit to the end consumer is between £m and £m. The combination of Viking Link and NSN Interconnector returns an overall benefit between £m and £m. For both of these combinations Viking Link can only provide a maximum of £m of benefit.

Value to the Interconnector:

The values presented here for the interconnectors are the "savings" resulted for the end-consumer and not the potential earning for the interconnector(s). Factors such as increase in competition in the provision of this service (for example multiple HVDC Interconnectors competing to provide the service) and the introduction of new services (for example from DSR and/or renewable generation) is expected to limit the potential value that interconnector(s) could extract in providing this service to below the values identified in this report.

4.1.2 Reactive response

The results for analysis undertaken in examining the potential benefits that the Viking Link interconnector can provide in respect to provision of voltage support is in the range of £m to £m per annum, when compared to investment of reactive response in form of shunt reactor and STATCOM respectively.

The results were obtained based on calculations that East Coast area required 258MVAr reactive compensation from the interconnector to keep the voltage within the operational limits. This avoided capital costs required for investment for a shunt reactor and STATCOM are £4.7m and £24m respectively.

However, if the Viking Link interconnector enters the reactive market then the reactive response benefits will depend on the market price for the reactive response service.

Reactive support is a local oriented phenomenon therefore the Viking Link in combination with other interconnectors will not change the benefits identified.

4.1.3 Boundary Capability

4.1.3.1 Viking Link INTERCONNECTOR only

The active limits are thermal for Viking Link so no additional voltage or stability studies were undertaken for Viking Link or its combinations.

4.1.3.2 Displaced Capital Investment

As indicated by the boundary capability analysis, Viking Link alone was found to provide no additional boundary capability. The displaced investment for Viking Link and all other studied combinations which include Viking Link is shown in the table below.

Interconnector combination	Viking Link Only	All Interconnectors	All except Greenlink	All except NSN	IFA2, FAB & Viking Link	NSN and Viking Link
Potential total investment displaced	£0 m	Up to £91.7 m	Up to £91.7 m	Up to £48.4m	Up to £48.4m	Up to £43.3 m
Annualised potential displaced investment[10] cost	£0 m	Up to £4.9 m	Up to £4.9 m	Up to £2.6 m	Up to £2.6 m	Up to £2.3 m

Table 9: Displaced Investment Benefit of Viking Interconnector

[10] Annualised capital costs including cost of finance based on an assumed 40 year asset life.

4.1.4 Constraint management

This section outlines the annual operational cost implications of Viking Link and associated combinations for the GB network in 2020. The analysis is based on 2020 forecast of GB network, which includes reinforcements for certain key boundaries[11]. The analysis results, which are summarised in the table below, have been presented in 2014 price base.

Interconnector combinations	Viking Link Only	All Interconnectors	All except Greenlink	All except NSN	IFA2, FAB & NSN	NSN and Viking Link
Central Case	-£1 m	-£14 m	-£1 m	-£14 m	-£9 m	-£12 m
Upper Limit	£4 m	£21 m	£28 m	£11 m	£9 m	£14 m
Lower Limit	-£10 m	-£56 m	-£41 m	-£34 m	-£29 m	-£34 m

Table 10: Annual Operational Cost Implication of Viking Interconnector

As outlined in the methodology in Appendix C, the operational cost implications of a certain interconnector or combinations are a function of energy prices in interconnected markets across Europe and the modelled system marginal price for GB in 2020. The analysis has been performed for a range of price forecasts for European markets. Furthermore, the analysis considers a price range for constraining interconnector flow, which includes week-ahead trades and SO to SO actions. The central case includes base market prices and base interconnector constraint costs. The upper and lower limits include sensitivities on these prices and costs.

The analysis demonstrates that the addition of Viking Link only could increase operational costs of the GB network in 2020 by up to £10m per annum. However, a change in price assumptions (including European market prices and constraint cost for interconnectors) could result in a reduction in operational costs of up to £4m per annum. This reduction in operational costs of GB network is considered as a benefit of the interconnector. The analysis for Viking Link based interconnector combinations suggests that the operational costs implications could range from an increase of approximately £56m per annum to a reduction of some £28m per annum.

4.2 Summary of results

Table 11 summarises the monetised benefits for the services areas for the Viking Link Interconnector and five additional combinations. Table 12 presents the annual operational cost implications for Viking Link and the same combinations.

The tables present ranges of annual values in £m (2014 prices) for each service and operational cost.

[11] The analysis undertaken for NSN and any related combinations assume additional reinforcement of B7a. Details of this reinforcement, such as capital cost, need to be developed further.

£m	Viking Link only		All Interconnector		Viking Link and others apart from Greenlink		Viking Link and others apart from NSN		French and Viking Link only		NSN with Viking Link only	
	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit
Frequency response	X	X	X	X	X	X	X	X	X	X	X	X
Black start	X	X	X	X	X	X	X	X	X	X	X	X
Reactive response (shunt reactor/STATCOM)	X	X	X	X	X	X	X	X	X	X	X	X
Boundary capability delivered (Annualised displaced investment)	0	0	0	4.9	0	4.9	0	2.6	0	2.6	0	2.3
Total	**23.4**	**46.1**	**116.5**	**155.7**	**115.5**	**155.7**	**82.1**	**145.3**	**81.1**	**145.3**	**56.8**	**112.6**

Table 11: Value of Viking Link Interconnector and associated Interconnector combinations

£m	Viking Link only		All Interconnector		Viking Link and others apart from Greenlink		Viking Link and others apart from NSN		French and Viking Link only		NSN with Viking Link only	
	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit
Constraint management (Annual operational cost implications)	**-10**	**4**	**-56**	**21**	**-41**	**28**	**-34**	**11**	**-29**	**9**	**-34**	**14**

Table 12: Annual Operational Cost Implications of Viking Interconnector and associated Interconnector combinations

5 Analysis of Greenlink Interconnector to Ireland

5.1 Introduction

The proposed 500 MW Interconnector is assumed to connect to the GB transmission system at Pembroke in South West Wales.

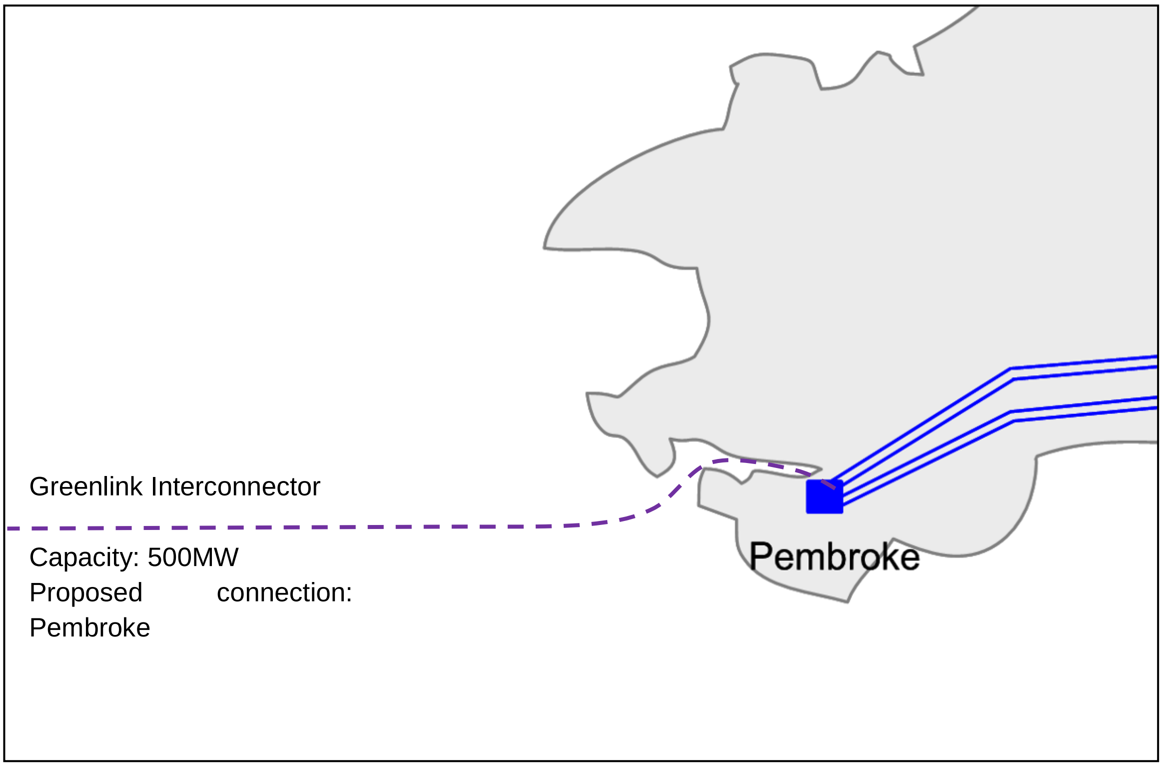


Figure 13: Proposed Greenlink Interconnector connection to existing GB Transmission System

The Interconnector cable route shown on this map is indicative only

The monetised benefits for the services which the Greenlink Interconnector could provide have been considered for the combinations identified below:

- Greenlink only
- All Interconnector
- Greenlink and others apart from NSN
- Greenlink and others apart from Viking Link
- Greenlink and French only

5.1.1 Frequency response

From a technical standpoint, the Greenlink Interconnector has not been studied due to the Irish network being a significantly smaller system and the potential effects it would have on system stability of the Irish network, due to much lower level of inertia on their system. For this reason, all Greenlink Interconnector combinations have not been considered further with respect to frequency response. However, Ireland's transmission system does carry normal frequency response to cater for losses on their system. Therefore, whilst provision of service from Ireland would be significantly less than that provided by the other interconnectors under consideration, further joint investigations are required with EirGrid to determine the potential for the provision of fast response.

5.1.2 Reactive response

The results for Greenlink interconnector are compared only with investment of shunt reactor in the network, due to the low level of reactive compensation that is required in the network. The results demonstrate that there are benefits very small in comparison to investment in reactive response in form of shunt reactor and the benefits are £m per annum, when compared to reactive response in form of shunt reactor.

The results were obtained based on calculations that the South Wales area required 100MVAr reactive compensation from the interconnector to keep the voltage within the operational limits. The smaller range of reactive power for STATCOM is 200MVAr therefore comparison with investment in STATCOM was not taken into consideration.

However, if the Greenlink interconnector enters the reactive market then the benefits will depend on the price in the market for the reactive response service.

Reactive support is a local oriented phenomenon therefore the Greenlink in combination with other interconnectors will not change the benefits identified.

5.1.3 Boundary Capability

5.1.3.1 Greenlink INTERCONNECTOR only

No boundary contribution can be attributed to Greenlink though this might change in future.

5.1.3.2 Displaced Capital Investment

As indicated by the boundary capability analysis, at this stage no boundary capability increase has been attributed to Greenlink. The displaced investment for Greenlink and all other studied combinations which include Greenlink is shown in the table below.

Interconnector combination	Greenlink Only	All Interconnectors	All except NSN	All except Viking Link	IFA2, FAB & Greenlink
Potential total investment displaced	£0 m	Up to £91.7 m	Up to £48.4 m	Up to £91.7 m	Up to £48.4 m
Annualised potential displaced investment[12] cost	£0 m	Up to £4.9 m	Up to £2.6 m	Up to £4.9 m	Up to £2.6 m

Table 13: Displaced Investment Benefit of Greenlink Interconnector

5.1.4 Constraint management

This section outlines the annual operational cost implications of Greenlink and associated combinations for the GB network in 2020. The analysis is based on 2020 forecast of GB network, which includes reinforcements for certain key boundaries[13]. The analysis results, which are summarised in the table below, have been presented in 2014 price base.

Interconnector combinations	Greenlink Only	All Interconnectors	All except NSN	All except Viking Link	IFA2, FAB & Greenlink
Central Case	-£21 m	-£14 m	-£14 m	-£9 m	-£8 m
Upper Limit	-£9 m	£21 m	£14 m	£20 m	£8 m
Lower Limit	-£27 m	-£56 m	-£34 m	-£45 m	-£24 m

Table 14: Annual Operational Cost Implication of Greenlink Interconnector

As outlined in the methodology in Appendix C, the operational cost implications of a certain interconnector or combinations are a function of energy prices in interconnected markets across Europe and modelled system marginal price for GB in 2020. The analysis has been performed for a range of price forecasts for European markets. Furthermore, the analysis considers a price range for constraining interconnector flow, which includes week-ahead trades and SO to SO actions. The central case includes base market prices and base interconnector constraint costs. The upper and lower limits include sensitivities on these prices and costs.

The analysis demonstrates that the addition of Greenlink only could increase operational costs of the GB network in 2020 by up to £27m per annum. However, a change in price assumptions (including European market prices and constraint cost for interconnectors) could result in a smaller increase of approximately £9m per annum. As the addition of Greenlink only does not reduce operational costs of GB network, this interconnector is not considered to deliver any benefit in terms of constraint management. The analysis for Greenlink based interconnector

[12] Annualised capital costs including cost of finance based on an assumed 40 year asset life.

[13] The analysis undertaken for NSN and any related combinations assume additional reinforcement of B7a. Details of this reinforcement, such as capital cost, need to be developed further.

combinations suggests that the operational costs implications could range from an increase of approximately £56m per annum to a reduction of some £21m per annum. However, it should be noted that Greenlink has not been subject to the CION process, this may identify a more optimum connection point, which could mitigate against these increased constraint costs.

Opportunities might arise for constraint management involving other interconnectors to Ireland if relevant reinforcements on the onshore Irish network take place and the necessary agreements are made.

5.2 Summary of results

Table 15 summarises the monetised benefits for the services areas for the Greenlink Interconnector and five additional combinations. Table 16 presents the annual operational cost implications for Greenlink and the same combinations.

The tables present ranges of annual values in £m (2014 prices) for each service and operational cost.

£m	Greenlink only		All Interconnector		Greenlink and others apart from NSN		Greenlink and others apart from Viking Link		French and Greenlink only	
	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit
Frequency response	X	X	X	X	X	X	X	X	X	X
Black start	X	X	X	X	X	X	X	X	X	X
Reactive response	X	X	X	X	X	X	X	X	X	X
Boundary capability delivered (Annualised displaced investment)	0	0	0	4.9	0	2.6	0	4.9	0	2.6
Total	**0**	**0**	**116.5**	**155.7**	**82.1**	**145.3**	**90.1**	**148.6**	**56.6**	**113.2**

Table 15: Value of Greenlink Interconnector and associated Interconnector combinations

Note that for the combinations involving interconnectors in addition to Greenlink, the benefits are not attributable to Greenlink.

£m	Greenlink only		All Interconnector		Greenlink and others apart from NSN		Greenlink and others apart from Viking Link		French and Greenlink only	
	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit
Constraint management (Annual operational cost implications)	**-27**	**-9**	**-56**	**21**	**-34**	**11**	**-45**	**20**	**-24**	**8**

Table 16: Annual Operational Cost Implication of Greenlink Interconnector and associated combinations

6 Analysis of IFA2 Interconnector to France

6.1 Introduction

The proposed 1000 MW Interconnector would connect to the GB transmission system between Botley Wood and Fawley in Hampshire in southern England.

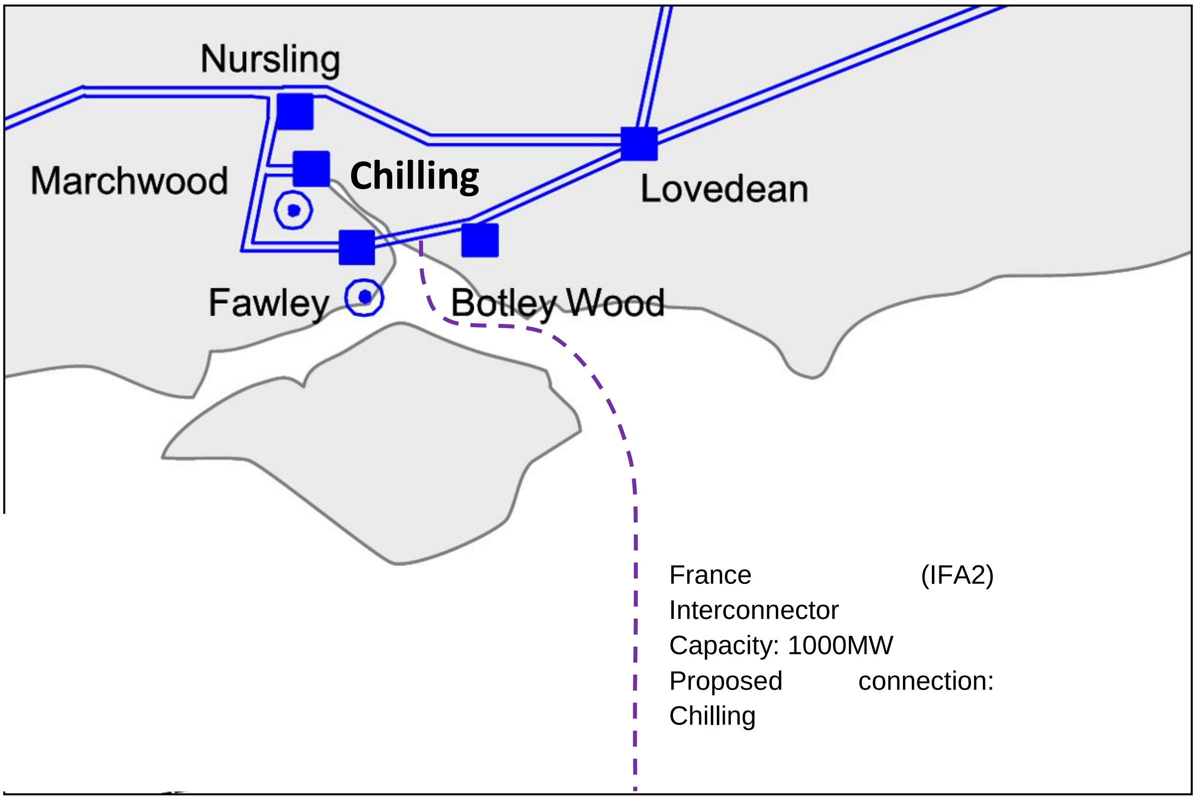


Figure 14: Proposed IFA2 Interconnector connection to existing GB Transmission system

The Interconnector cable route shown on this map is indicative only

The monetised benefits for the services which the IFA2 Interconnector could provide have been considered for the combinations identified below:

- IFA2 only
- All Interconnector
- IFA2 and others apart from Greenlink
- IFA2 and others apart from NSN
- IFA2 and other apart from Viking Link
- Both French only
- Both French and Greenlink only
- Both French and NSN only
- Both French and Viking Link only

6.1.1 Frequency response

The changes expected in the generation mix will increase the volume of required frequency response by 2020. An alternative to increase the volume of frequency response is to provide faster response via HVDC Interconnectors.

The potential benefit to the end consumer if IFA2 was to provide fast response when considered in isolation (that is the only HVDC Interconnector providing this service) is between £m and £m per annum, assuming that the service is limited to either **5%** or **10%** of the capacity of the link being made available to provide fast response respectively (capacity being restricted to this value to minimise both the impact on potential trading opportunities and impact on external systems providing this service).

When all Interconnectors (except Greenlink) are assumed to be in service, the potential benefit to the end consumer is a reduction in costs to provide this service in the range £m and £m but the IFA2 contribution to the saving remains in the region £m to £m per annum.

In other combinations:

Assuming both IFA2 and FAB are available to provide this service, the benefit to the end consumer is between £m and £m. The combination of both French (IFA2 and FAB) and NSN Interconnectors returns an overall benefit of between £m and £m. The combination of both French (IFA2 and FAB) and Viking Link Interconnectors returns an overall benefit of between £m and £m. For all of these combinations IFA2 can only provide a maximum of £m of benefit.

Value to the Interconnector:

The values presented here for the interconnectors are the “savings” resulted for the end-consumer and not the potential earning for the interconnector(s). Factors such as increase in competition in the provision of this service (for example multiple HVDC Interconnectors competing to provide the service) and the introduction of new services (for example from DSR and/or renewable generation) is expected to limit the potential value that interconnector(s) could extract in providing this service to below the values identified in this report.

6.1.2 Reactive Response

The results for analysis undertaken in examining the potential benefits that the IFA2 interconnector can provide in respect to provision of voltage support is in the range of £m to £m per annum, when compared to investment of reactive response in the form of shunt reactor and STATCOM respectively.

The results were obtained based on calculations that East Coast area required 200MVAr reactive compensation from the interconnector to keep the voltage within the operational limits.

However, if the IFA2 interconnector enters the reactive market then the reactive response benefits will depend on the price of the reactive response service.

Reactive support is a local oriented phenomenon therefore the IFA2 Interconnector in combination with other interconnectors will not change the benefits identified.

6.1.3 Boundary Capability

6.1.3.1 Boundary B13

Studies have demonstrated that the contribution from IFA2 HVDC would increase the voltage collapse limit by **80MW**. If both IFA2 and FAB are in operation the B13 voltage collapse limit can be increased by a total of **200MW**. Studies have demonstrated that the contribution from IFA2 HVDC would increase the voltage compliance limit by **534MW**. The voltage compliance limit can be increased by 534 MW with the connection of IFA2, as IFA2 relieves the under-voltage on the Axminster 400kV circuit.

The collapse limit is dependent on the voltage support that is available near the point of voltage collapse as well as the impedance of the network in the region. The effectiveness of reactive support at both ends of a circuit route is more than double in comparison with having the reactive injection from an interconnector at one site only.

6.1.3.2 Boundary SC1 - voltage collapse limit

Studies have demonstrated that the contribution from IFA2 HVDC would increase the voltage collapse limit by **40MW**.

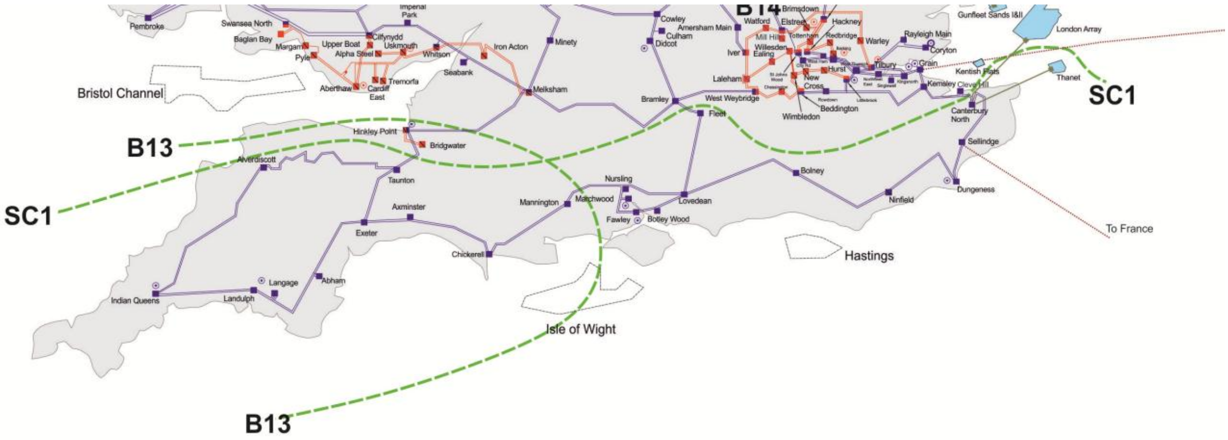


Figure 17: GB Boundaries impacts by IFA2 Interconnector

6.1.3.3 Displaced Capital Investment

From 2020, IFA2 could provide additional voltage support which as described above, results in additional boundary capability of up to 534 MW on B13 and 40 MW on SC1. This additional capability has the potential to displace future investment across these boundaries. The displaced investment for IFA2 and all other studied combinations which include IFA2 is shown in the table below.

Interconnector combination	IFA2 Only	All Interconnectors	All except Greenlink	All except NSN	All except Viking Link	IFA2 and FAB	IFA2, FAB, & Greenlink	IFA2, FAB & NSN	IFA2, FAB & Viking Link
Potential total investment displaced	Up to £48.4 m	Up to £91.7 m	Up to £91.7 m	Up to £48.4 m	Up to £91.7 m	Up to £48.4 m	Up to £48.4 m	Up to £91.7 m	Up to £48.4 m
Annualised potential displaced investment[14] cost	Up to £2.6 m	Up to £4.9 m	Up to £4.9 m	Up to £2.6 m	Up to £4.9 m	Up to £2.6 m	Up to £2.6 m	Up to £4.9 m	Up to £2.6 m

Table 17: Displaced Investment Benefit of IFA2 Interconnector

[14] Annualised capital costs including cost of finance, based on an assumed 40 year asset life.

6.1.4 Constraint management (operational cost implications)

This section outlines the annual operational cost implications of IFA 2 and associated combinations for the GB network in 2020. The analysis is based on 2020 forecast of GB network, which includes reinforcements for certain key boundaries[15]. The analysis results, which are summarised in the table below, have been presented in 2014 price base.

Interconnector combinations	IFA2 Only	All Interconnectors	All except Greenlink	All except NSN	All except Viking Link	IFA2 and FAB	IFA2, FAB, & Greenlink	IFA2, FAB & NSN	IFA2, FAB & Viking Link
Central Case	£4 m	-£14 m	-£1 m	-£14 m	-£9 m	£0 m	-£8 m	-£1 m	-£9 m
Upper Limit	£8 m	£21 m	£28 m	£11 m	£20 m	£11 m	£8 m	£24 m	£9 m
Lower Limit	-£4 m	-£56 m	-£41 m	-£34 m	-£45 m	-£10 m	-£24 m	-£40 m	-£29 m

Table 18: Annual Operational Cost Implications of IFA2 Interconnector

As outlined in the methodology in Appendix C, the operational cost implications of a certain interconnector or combinations are a function of energy prices in interconnected markets across Europe and the modelled system marginal price for GB in 2020. The analysis has been performed for a range of price forecasts for European markets. Furthermore, the analysis considers a price range for constraining interconnector flow, which includes week-ahead trades and SO to SO actions. The central case includes base market prices and base interconnector constraint costs. The upper and lower limits include sensitivities on these prices and costs.

The analysis demonstrates that the addition of IFA 2 only could increase operational costs of the GB network in 2020 by up to £4m per annum. However, a change in price assumptions (including European market prices and constraint cost for interconnectors) could result in a reduction in operational costs of up to £8m per annum. This reduction in operational costs of GB network is considered as a benefit of the interconnector. The analysis for IFA 2 based interconnector combinations suggests that the operational costs implications could range from an increase of approximately £56m per annum to a reduction of some £28m per annum.

6.2 Summary of results

Table 19 summarises the monetised benefits for the services areas for the IFA2 Interconnector and five additional combinations. Table 20 presents the annual operational cost implications for IFA2 and the same combinations.

The tables present ranges of annual values in £m (2014 prices) for each service and operational cost.

[15] The analysis undertaken for NSN and any related combinations assume additional reinforcement of B7a. Details of this reinforcement, such as capital cost, need to be developed further.

£m	IFA2 only		All Interconnector		IFA2 and others apart from Greenlink		IFA2 and others apart from NSN		IFA2 and others apart from Viking Link		Both French only		Both French and Greenlink only		Both French and NSN only		Both French and Viking Link only	
	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit
Frequency response	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Black start	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Reactive response	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Boundary capability delivered (Annualised displaced investment)	0	2.6	0	4.9	0	4.9	0	2.6	0	4.9	0	2.6	0	2.6	0	4.9	0	2.6
Total	**22.2**	**48**	**116.5**	**155.7**	**115.5**	**155.7**	**82.1**	**145.3**	**90.1**	**148.6**	**56.6**	**113.2**	**56.6**	**113.2**	**90.1**	**148.6**	**81.1**	**145.3**

Table 19: Value of IFA2 Interconnector and associated Interconnector combination

£m	IFA2 only		All Interconnector		IFA2 and others apart from Greenlink		IFA2 and others apart from NSN		IFA2 and others apart from Viking Link		Both French only		Both French and Greenlink only		Both French and NSN only		Both French and Viking Link only	
	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit
Constraint management (Annual operational cost implications)	**-4**	**8**	**-56**	**21**	**-41**	**28**	**-34**	**11**	**-45**	**20**	**-10**	**11**	**-24**	**8**	**-40**	**24**	**-29**	**9**

Table 20: Annual Operational Cost Implications of IFA2 Interconnector and associated Interconnector combination

7 Analysis of FAB Interconnector to France

7.1 Introduction

The proposed 1400 MW Interconnector would connect to the GB transmission system at Exeter in the south west of England.

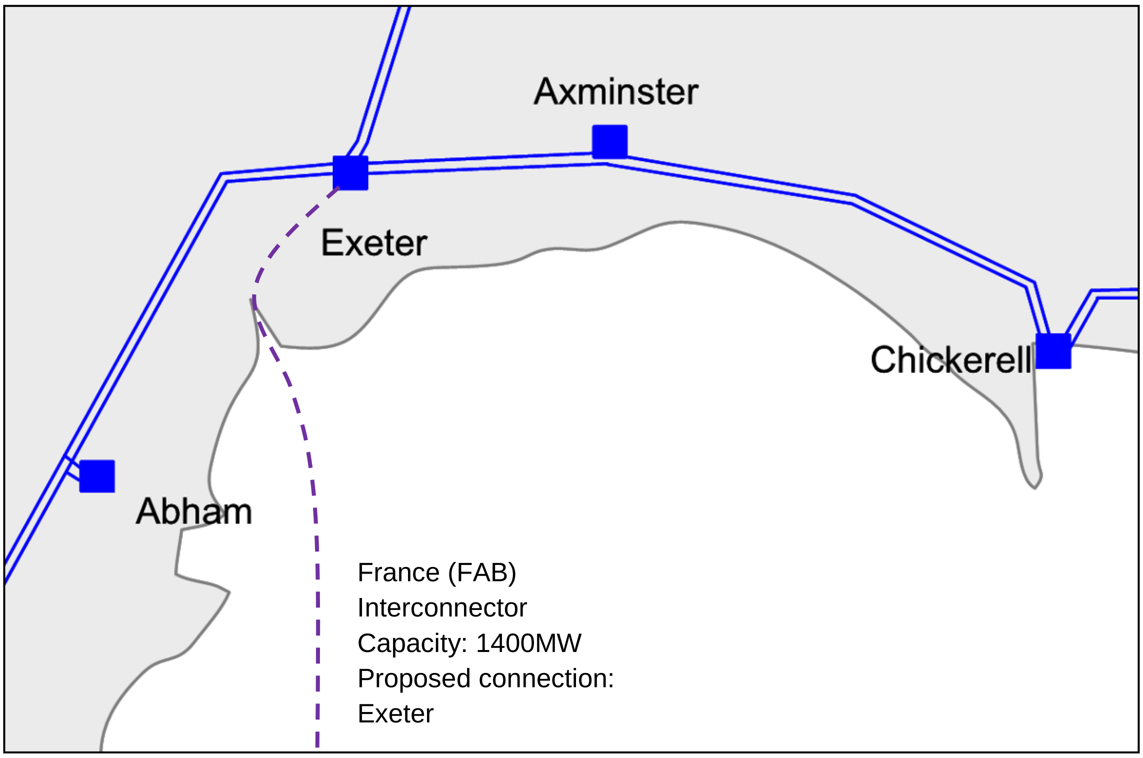


Figure 18: Proposed FAB Interconnector connection to existing GB Transmission System

The Interconnector cable route shown on this map is indicative only

7.2 Summary of results

The monetised benefits for the services which the FAB Interconnector could provide have been considered for the combinations identified below:

- FAB only
- All Interconnector
- FAB and others apart from Greenlink
- FAB and others apart from NSN
- FAB and other apart from Viking Link
- Both French only
- Both French and Greenlink only
- Both French and NSN only
- Both French and Viking Link only

7.2.1 Frequency response

The changes expected in the generation mix will increase the volume of required frequency response by 2020. An alternative to increase the volume of frequency response is to provide faster response via HVDC Interconnectors.

The potential benefit to the end consumer if FAB was to provide fast response when considered in isolation (that is the only HVDC interconnector providing this service) is between £m and £m per annum, assuming that the service is limited to either **5%** or **10%** of capacity of the link being made available to provide fast response respectively (capacity being restricted to this value to minimise both the impact on potential trading opportunities and impact on external systems providing this service).

When all Interconnectors (except Greenlink) are assumed to be in service, the potential benefit to the end consumer is a reduction in costs to provide this service in the range £m and £m but the FAB contribution to the saving remains in the region £m to £m per annum.

In other combinations:

Assuming both IFA2 and FAB French are available to provide this service, the benefit to the end consumer is between £m and £m. The combination of both French (IFA2 and FAB) and NSN Interconnectors returns an overall benefit of between £m and £m. The combination of both French (IFA2 and FAB) and Viking Link Interconnectors returns a benefit of between £m and £m. For all of these combinations FAB can only provide a maximum of £m of benefit.

Value to the Interconnector:

The values presented here for the interconnectors are the “savings” resulted for the end-consumer and not the potential earning for the interconnector(s). Factors such as increase in competition in the provision of this service (for example multiple HVDC Interconnectors competing to provide the service) and the introduction of new services (for example from DSR and/or renewable generation) is expected to limit the potential value that interconnector(s) could extract in providing this service to below the values identified in this report.

7.2.2 Reactive response

The results for analysis undertaken in examining the potential benefits that the FAB interconnector can provide in respect to provision of voltage support is in the range of £m to £m per annum when compared to investment of reactive response in the form of shunt reactor and investment of STATCOM respectively.

The results were obtained based on calculations that South East Coast area required 300MVAr reactive compensation from the interconnector to keep the voltage within the operational limits.

However, if the FAB interconnector enters the reactive market then the reactive response benefits will depend on the market price of the reactive response service.

Reactive support is a local oriented phenomenon therefore the FAB in combination with other interconnectors will not change the benefits identified.

7.2.3 Boundary Capability

7.2.3.1 Boundary B13

Studies have demonstrated that the contribution from FAB HVDC would increase the voltage collapse limit by **80MW**. If both IFA2 and FAB are in operation the B13 voltage collapse limit can be increased by a total of **200MW**.

The collapse limit is dependent on the voltage support that is available near the point of voltage collapse as well as the impedance of the network in the region. The effectiveness of reactive support at both ends of a circuit route is more than double in comparison with having the reactive injection from an interconnector at one site only.

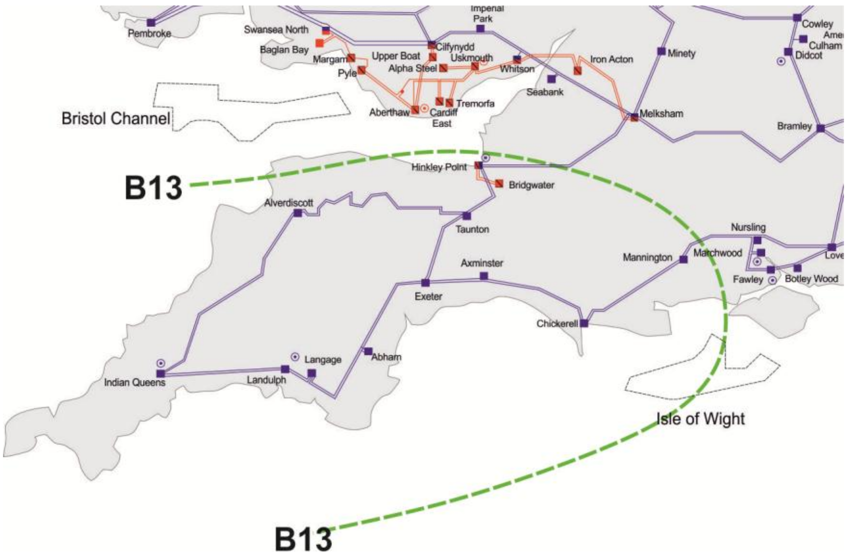


Figure 21: GB Boundaries affected by FAB Interconnector

7.2.3.2 Displaced Capital Investment

From 2020, FAB could provide additional voltage support which would result in a boundary capability increase of up to 80 MW on B13; this capability can be increased to 200 MW when both FAB and IFA2 are connected. This additional capability has the potential to displace future investment across this boundary. The displaced investment due to FAB and all other studied combinations which include FAB is shown in the table below.

Interconnector combination	FAB Only	All Interconnectors	All except Greenlink	All except NSN	All except Viking Link	IFA2 and FAB	IFA2, FAB, & Greenlink	IFA2, FAB & NSN	IFA2, FAB & Viking Link
Potential total investment displaced	Up to £6.5 m	Up to £91.7 m	Up to £91.7 m	Up to £48.4 m	Up to £91.7 m	Up to £48.4 m	Up to £48.4 m	Up to £91.7 m	Up to £48.4 m
Annualised potential displaced investment[16] cost	Up to £0.4 m	Up to 4.9 m	Up to £4.9 m	Up to £2.6 m	Up to £4.9 m	Up to £2.6 m	Up to £2.6 m	Up to £4.9 m	Up to £2.6 m

Table 21: Displaced Investment Benefit of FAB Interconnector

7.2.4 Constraint management *(operational cost implications)*

This section outlines the annual operational cost implications of FAB and associated combinations for the GB network in 2020. The analysis is based on 2020 forecast of GB network, which includes reinforcements for certain key boundaries[17]. The analysis results, which are summarised in the table below, have been presented in 2014 price base.

Interconnector combinations	FAB Only	All Interconnectors	All except Greenlink	All except NSN	All except Viking Link	IFA2 and FAB	IFA2, FAB, & Greenlink	IFA2, FAB & NSN	IFA2, FAB & Viking Link
Central Case	£4 m	-£14 m	-£1 m	-£14 m	-£9 m	£0 m	-£8 m	-£1 m	-£9 m
Upper Limit	£12 m	£21 m	£28 m	£11 m	£20 m	£11 m	£8 m	£24 m	£9 m
Lower Limit	-£6 m	-£56 m	-£41 m	-£34 m	-£45 m	-£10 m	-£24 m	-£40 m	-£29 m

Table 22: Annual Operational Cost Implications of FAB Interconnector

As outlined in the methodology in Appendix C, the operational cost implications of a certain interconnector or combinations are a function of energy prices in interconnected markets across Europe and modelled system marginal price for GB in 2020. The analysis has been performed for a range of price forecasts for European markets. Furthermore, the analysis considers a price range for constraining interconnector flow, which includes week-ahead trades and SO to SO actions. The central case includes base market prices and base interconnector constraint costs. The upper and lower limits include sensitivities on these prices and costs.

[16] Annualised capital cost including cost of finance based on an assumed 40 year asset life.
[17] The analysis undertaken for NSN and any related combinations assume additional reinforcement of B7a. Details of this reinforcement, such as capital cost, need to be developed further.

The analysis demonstrates that the addition of FAB only could increase operational costs of the GB network in 2020 by up to £6m per annum. However, a change in price assumptions (including European market prices and constraint cost for interconnectors) could result in a reduction in operational costs of up to £12m per annum. This reduction in operational costs of GB network is considered as a benefit of the interconnector. The analysis for FAB based interconnector combinations suggest that the operational costs implications could range from an increase of approximately £56m per annum to a reduction of some £28m per annum.

7.3 Summary of results

Table 23 summarises the monetised benefits for the services areas for the FAB Interconnector and five additional combinations. Table 24 presents the annual operational cost implications for FAB and the same combinations.

The tables present ranges of annual values in £m (2014 prices) for each service and operational cost.

£m	FAB only		All Interconnector		FAB and others apart from Greenlink		FAB and others apart from NSN		FAB and others apart from Viking Link		Both French only		Both French and Greenlink only		Both French and NSN only		Both French and Viking Link only	
	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit
Frequency response	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Black start	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Reactive response	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Boundary capability delivered (Annualised displaced investment)	0	0.4	0	4.9	0	4.9	0	2.6	0	4.9	0	2.6	0	2.6	0	4.9	0	2.6
Total	**32.4**	**63.5**	**116.5**	**155.7**	**115.5**	**155.7**	**82.1**	**145.3**	**90.1**	**148.6**	**56.6**	**113.2**	**56.6**	**113.2**	**90.1**	**148.6**	**81.1**	**145.3**

Table 23: Value of FAB Interconnector and associated Interconnector Combination

£m	FAB only		All Interconnector		FAB and others apart from Greenlink		FAB and others apart from NSN		FAB and others apart from Viking Link		Both French only		Both French and Greenlink only		Both French and NSN only		Both French and Viking Link only	
	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit	Lower limit	Upper limit
Constraint management (Annual operational cost implications)	**-6**	**12**	**-56**	**21**	**-41**	**28**	**-34**	**11**	**-45**	**20**	**-10**	**11**	**-24**	**8**	**-40**	**24**	**-29**	**9**

Table 24: Annual Operational Cost Implications of FAB Interconnector and associated Interconnector Combination

8 Appendices

Appendix A

Assessments Methodology – Frequency Response

This appendix describes the methodologies for assessing the potential frequency response benefits. It covers the evaluation of the potential for interconnectors to provide frequency response, their respective value, and how various combinations will be studied. The process which is followed to calculate the value of interconnectors to provide frequency response is described below:

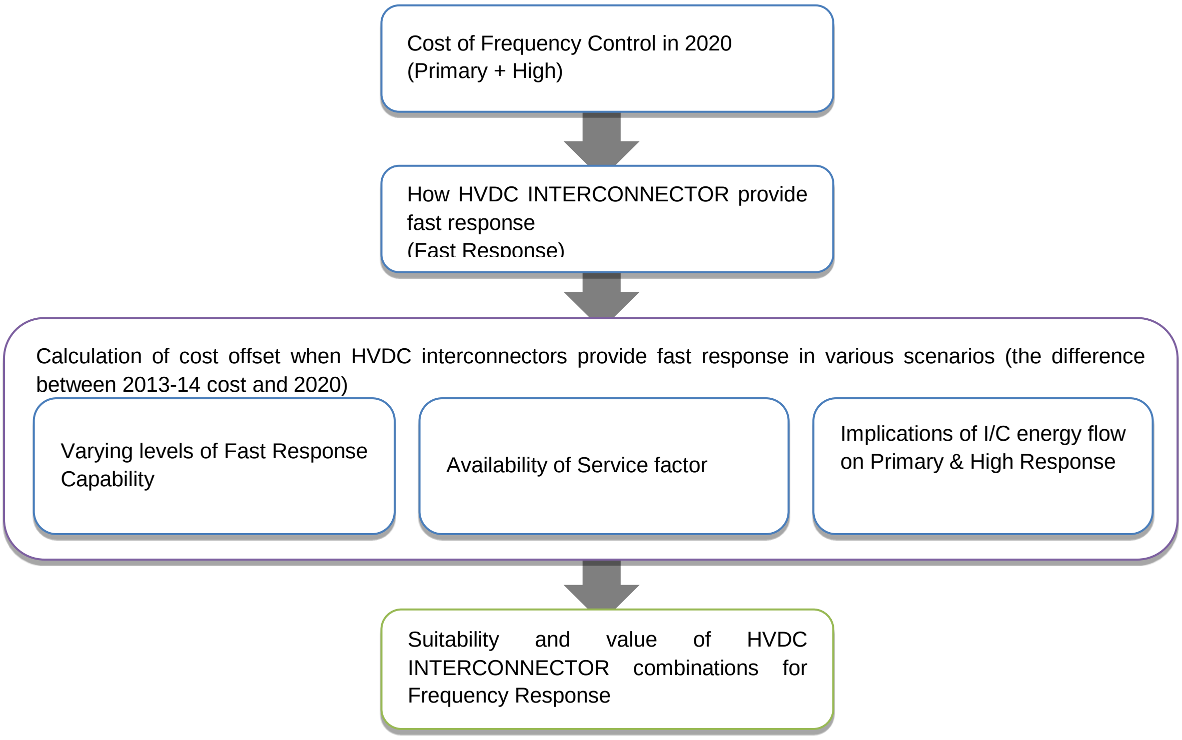


Figure A1: Methodology for calculation of value of HVDC INTERCONNECTOR to provide frequency response

This process involves calculating the cost of providing primary/high response considering the factors such as size of largest infeed, and system inertia for the studied scenario. These costs are calculated based on the 2013/2014 dispatch model developed and scaled based on Gone Green 2020. Once the cost of providing frequency response is calculated, this will be compared against the value of fast response which can be provided by HVDC Interconnectors. The offset provides the overall value of Interconnectors providing Frequency Response.

1. Suitability and Value Process

1.1 Cost of Frequency Control in 2020

National Grid incurs costs in managing system frequency. These costs are made up of a Holding Payment (£/MWh), and a Response Energy Payment (£/MWh).

The level of response required varies depending on a number of key factors such as:

A. Demand level
B. Amount and type of generation running on the system which influences the level of inertia on the system and also the ramp rate amongst the running generation fleet
C. Size of the largest infeed/outfeed which the system is to be secured against

Figure A2 illustrates the difference in response requirements overnight (settlement periods 47-14) and during the day (settlement periods 15-46). The difference is due to the lower load overnight, which means that any system event will have more of an impact (as a loss will represent a higher percentage of the overall level of load).

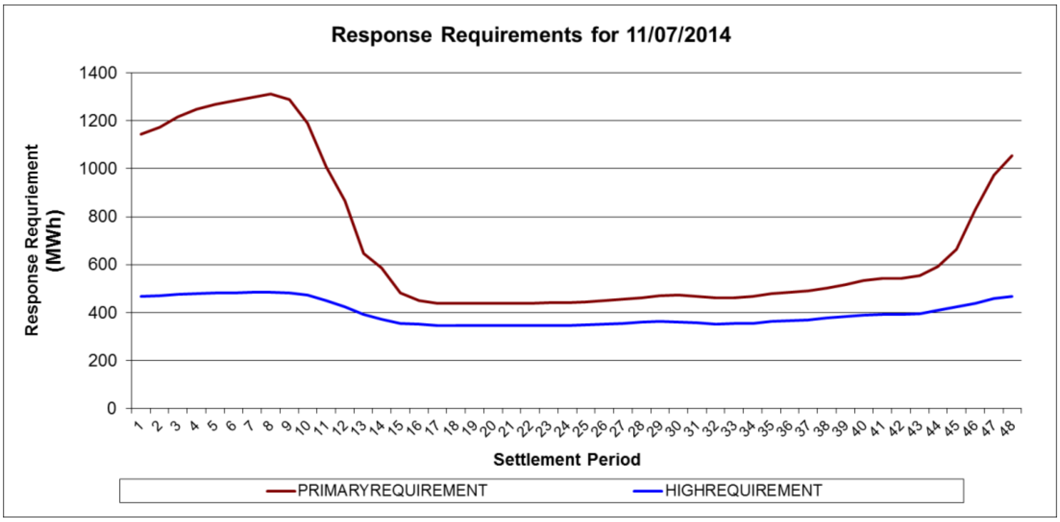
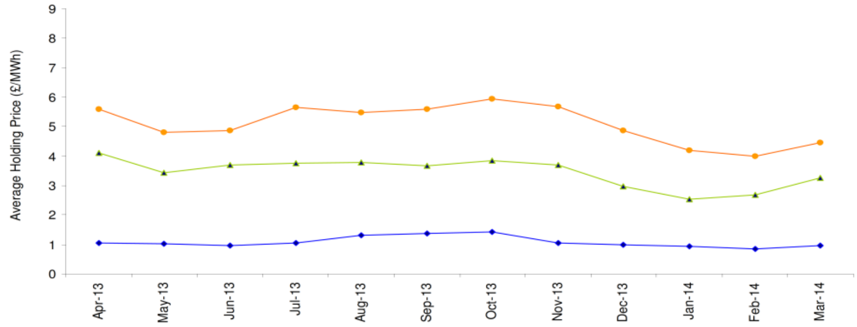


Figure A2 - Holding Response Requirement for a Typical Day (11th July 2014)

Figure A3 illustrates the average holding price for different types of response.



	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	Dec-13	Jan-14	Feb-14	Mar-14
Primary	4.11	3.44	3.70	3.77	3.80	3.68	3.85	3.69	2.98	2.52	2.67	3.25
Secondary	1.05	1.03	0.95	1.06	1.31	1.37	1.44	1.04	0.98	0.92	0.84	0.96
High	5.58	4.82	4.86	5.64	5.47	5.60	5.95	5.68	4.85	4.20	3.98	4.46

Figure A3 - Frequency Response Average Holding Price - April 2013-March 204

As described in the System Operability Framework the system inertia is reducing, and managing system frequency is therefore becoming more difficult. Under these conditions National Grid has three options:

1. Curtail the largest infeed/outfeed so the volume of holding response stays the same.
2. Constrain on Synchronous Generator to increase the level of inertia
3. Increase the volume of holding response, so the largest in-feed/out-feed is not constrained.

The future volume of response requirement is calculated based on future generation dispatch using the information available in National Grid's Future Energy Scenarios (FES). To calculate the volume of response required in a particular year (or % of time that the volume of response greater than xMW/s is required – "x" being the speed of response for each case) a future generation dispatch model enabling half-hourly inertia and response calculations has been developed. To validate this model, it has been compared against the 2013/14 actual generation dispatch and volume of response carried.

Figure A4 shows the process of calculating the future frequency response requirement.

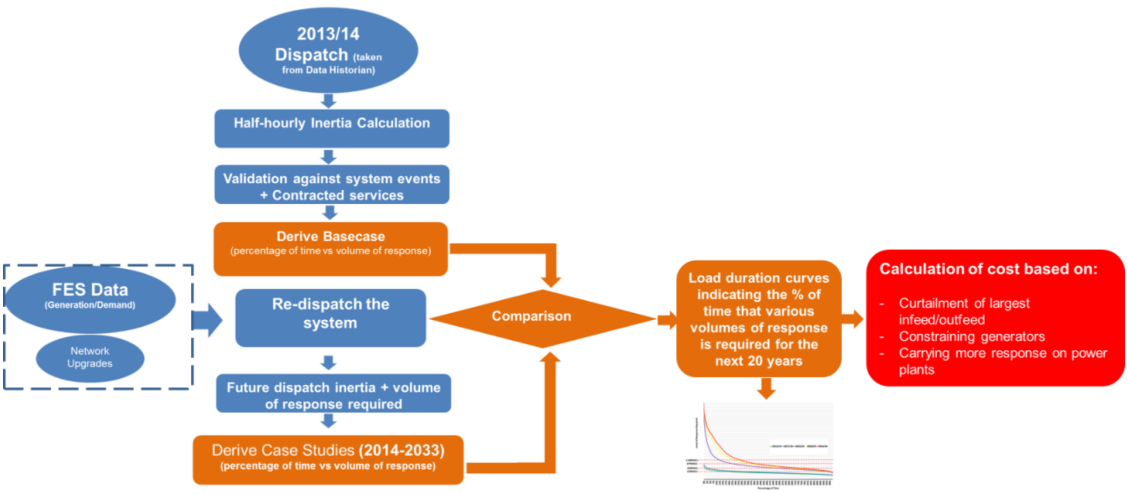


Figure A4: Methodology for Calculation of Future Primary Response Cost

The key information required to calculate the future cost of controlling system frequency can be derived from the process explained above. Figure A5[18] shows the percentage of time various response levels will be required over the next 20 years. For example, a response level of 1148MW/s is not required at all until 2023/24, but by 2033/34 it is required over 27% of the time.

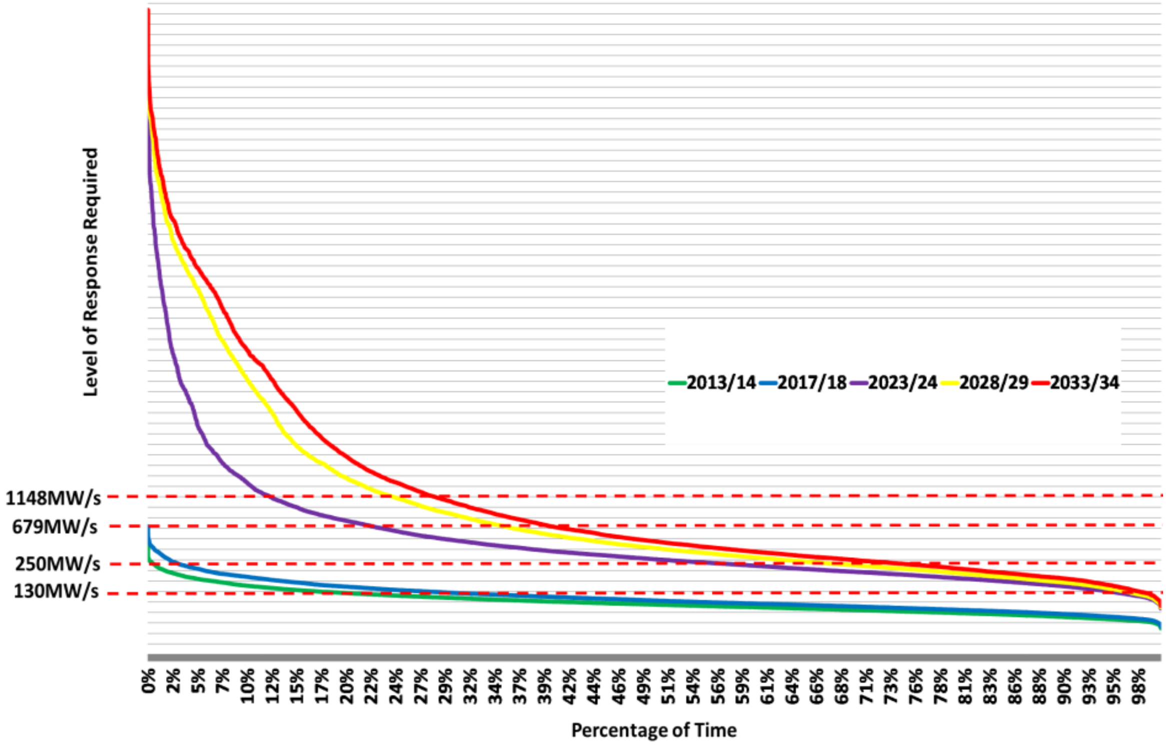


Figure A5 - Load Duration Curves showing the volume of response required for the next 20 years

There are three potential ***business as usual approaches*** to dealing with low system inertia and the resultant requirement for high volumes of response:

- Option (a) Curtailment of largest in-feed/out-feed;
- Option (b) Constraining generators (i.e. synchronise more generators to increase the level of inertia); or
- Option (c) Increase in volume of holding response.

The optimum cost has been calculated based on using the following cost figures, and ability to perform such actions (i.e. percentage of time that limiting flow across the Interconnectors may be possible).

To calculate the overall cost, the following £/MWh costs were assumed:

1. To curtail a large in-feed loss (other than Interconnector), such as a CCGT, a flat rate figure of £150/MWh was assumed.
2. To constrain on additional synchronous unit, the cost was assumed at £150/MWh (to increase system inertia).

[18] National Grid's System Operability Framework (SOF). Frequency Control Section.

SOF provides the Required Ramp Rate for 2020. The table below shows this:

RoCoF (Hz/s)	Slow Progression	Gone Green	Inertia GW/s	Action Time (to reach 49.2Hz)	Response Rate (MW/s)
0.125	2013/14	2013/14	360	9	185
0.2	2019/20	2018/19	225	4	400
0.22	2020/23	2019/20	205	3.4	489
0.25	2023/24	2020/21	180	2.4	679
0.3	2024/25	2021/22	150	1.2	1148

Table A1: Future Ramp Rate Requirements with decreasing system Inertia

With reduction of system inertia, the required ramp rate for frequency response increases significantly. Highlighted in green is the current response rate, and in red is the projected response rate for Gone Green 2020. The difference between these two values is approximately **300MW/s**. Therefore, in assessing the potential value for interconnectors, their capability to provide a partial or entire additional response requirement is considered.

1.2 How HVDC INTERCONNECTOR provides fast response

The HVDC interconnectors are capable of providing very fast response because of the nature of the technology used in the converters allowing them to change their power setpoint quickly. The rapid change of power setpoint allows fast injection of extra power into the system (in case of loss of an infeed), or increase of demand seen on the system (in case of loss of a large load, by reducing the power injection). This helps in controlling the system frequency, and given these actions can be provided very quickly, the HVDC interconnectors can offset significant increase in the cost of frequency control.

1.3 Calculation of cost offset when HVDC Interconnectors provide fast response in various scenarios

The calculations are based on the following forecasts:

- The cost of ***business as usual*** frequency response is estimated to cost the consumer £250 million per annum up to the year 2020 (currently £60m)
- The required ramp rate is calculated to be a maximum of 300MW/s by 2020

The ancillary frequency response service and associated values do not interfere with the market driven energy flow of an interconnector. No permanent curtailment of an interconnector in order to provide frequency response has been assumed, except in a frequency event.

Increased competition from interconnectors, generators and other Demand Side Response providers in providing Frequency Response would result in cannibalisation of values to a specific Interconnector. This has not been considered, and therefore further assessment would be required in order to determine the impact on value offered by an interconnector.

From a technical standpoint, the Greenlink Interconnector was not studied due the Irish network being a significantly smaller system and the effects it would have on system stability there, due to its much lower level of Inertia. For that reason, all Greenlink Interconnector combinations have been ruled out of calculation and analysis leaving 11 Interconnector combinations to be studied.

The following variables form the basis of calculating the value of fast response:

1.3.1 Percentage of capacity held for provision of fast response

For each combination, two loading levels of fast response are considered and their financial savings calculated. The levels are a percentage of the total installed capacity of each interconnector, or when studied in combination with other interconnectors. These levels are for 10% and 5% of total installed capacity. Interconnectors have the ability to provide a higher percentage of response, however further investigation would need to be conducted to ensure the foreign exporting system can cope with more extensive sudden increases/decrease in demand.

- Where the fast response capability is equal to or exceeds the required ramp rate of 300MW, it is assumed the maximum value is achieved. This is because the total available capability is equal to or more than what the system requires.

- Where the fast response capability is below the required ramp rate, the percentage of Fast Response capability against requirement is calculated and used to determine the partial saving.

For each combination, the total saving and the savings range are identified.

1.3.2 Availability of Service

In calculating the value of Fast Frequency Response, the availability of the Interconnectors has been incorporated into the overall values.

1.3.3 Implications of Interconnector energy flow on Primary and High Response

The ability to provide either Primary or High Response is restricted depending on the energy flow regime of an Interconnector:

- On full import into GB, only High Response service can be utilised.

- On full export from GB, only primary response service can be utilised.

- When the Interconnector is on Float, both services can be utilised.

Therefore, the savings impact the availability of each type of response. This is maintained at 10% and 5% throughout all calculations.

Primary and High Response services are incorporated into a cost factor, which are calculated from a historical average annual holding payment for each type of response. The flow regime of each Interconnector has been forecast based upon energy markets of different countries up to the year 2021. This is displayed as a percentage of total availability, split into; Import to GB, Export from GB, and Float (where market prices do not differ enough to warrant energy transfer). Initial Fast Response savings are used as a base for deducting flow regime limitations costs.

1.4 Technology used in HVDC converter and impact on the capability of the interconnector to provide fast response

The volume of response required (additional 300MW/s for 2020) is well within the capability of both CSC, and VSC technology. Therefore, fast frequency response is classed as technology neutral. However, when looking further ahead to 2030, the system Ramp Rate is forecasted to increase significantly further, in which case higher volumes of fast frequency response will be required. This favours VSC technology, which should be considered when choosing technology type.

Appendix B

Assessments Methodology – Reactive Response

This appendix describes the methodologies for assessing the potential reactive response benefits. The flow chart below summarises the proposed methodology to quantify the benefit of an Interconnector providing reactive capability. The key assumptions are summarised below;

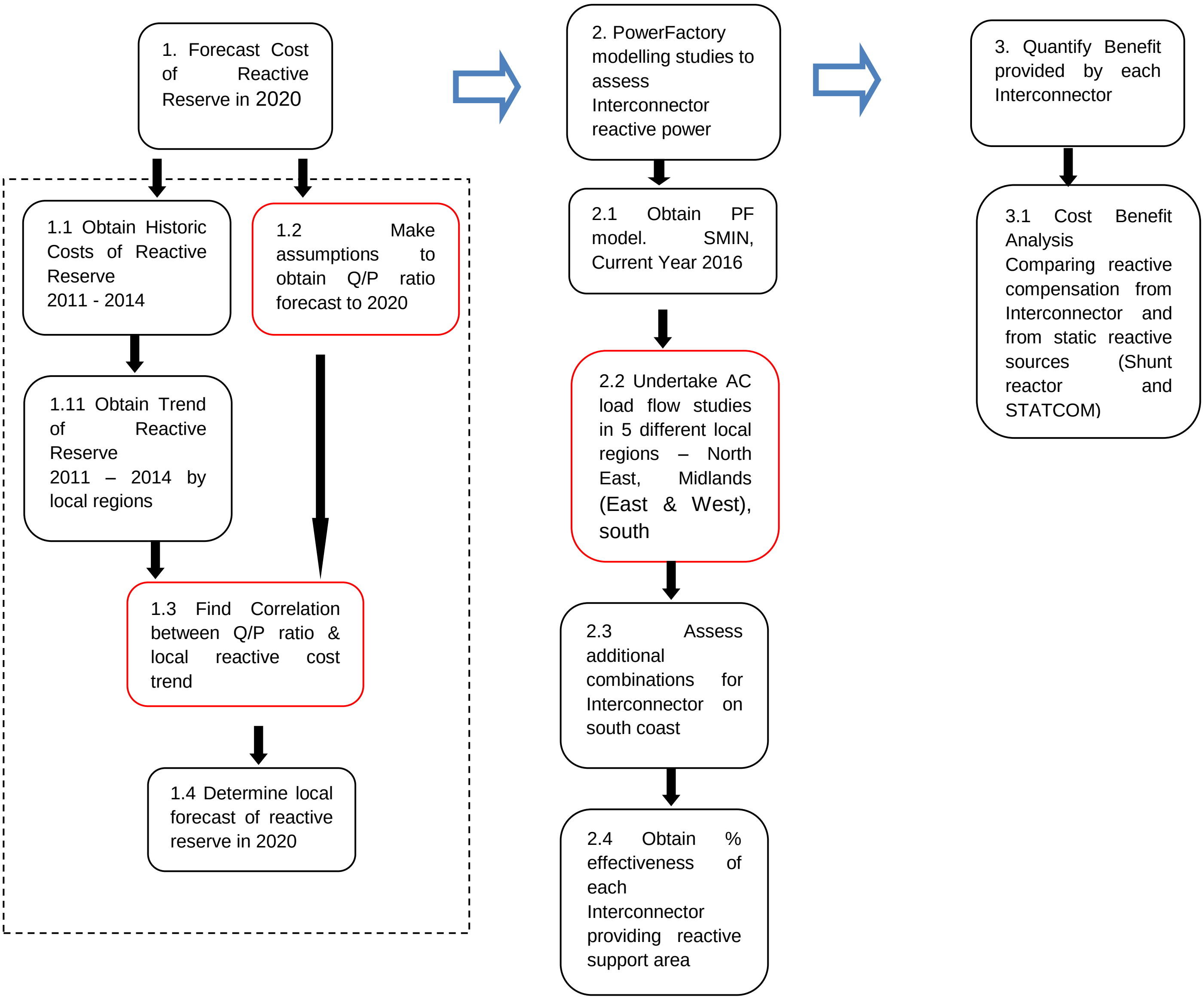


Figure B1 Process for determining reactive benefit

The summer minimum demand scenario with 16GW demand on the network for year 2016 was analysed. With reduced power demand and a tendency for higher system voltages during the summer months, fewer generators will operate and those that do run could do so at a reduced power factor output. Reactive power analysis are therefore usually performed for the summer minimum demand condition as this presents the limiting factors, but winter (peak) conditions may be studied as well to see the reactive power requirements during the peak period.

Winter peak demand, initial studies on Winter Peak demand demonstrated that only South East area will face reactive power requirements.

As it was highlighted in the methodology section above, the assumption of the costs and benefits of the Interconnector were based on historic data received on Reactive Support in the past years (2011 – 2013).

Combination of Interconnector – South East and South West

The potential benefits of only one combination of South East and south West Interconnector was proved not to bring any benefits, therefore it was not taken into consideration. Other combinations do not bring benefits due to the long distances between the areas of analysis.

Load Factor Sensitivity

It is important to mention that load factors for the unit were assumed based on historic data in the past. What would be the power factor of the contracted unit in the area is subject to forecast and future analysis. In this report the range and key factor that influence the benefits will be presented.

Sensitivity on costs

Considering that we do not know what the price for the Interconnector will be in the future years, we use the price for conventional generator as a reference price to calculate potential range of benefits for the Interconnector.

Technology of the Interconnector

The studies assumed that the Interconnector had VSC technology and not CSC as only this can provide reactive support.

Reactive Compensation Device – Investment in the network

In order to perform the economic analysis the comparison with static reactive device like STATCOM and Shunt Reactors were considered in the network. The study assumed that the costs for 200MVAr Shunt reactor on 400kV are £4.7m and STATCOM for 200MVar device on 400kV costs are £24m.

It is also important to mention that the location of reactive devices in the network is not decided by an optimal location. The reactive compensation devices are located by inspection in the areas/buses which by inspection will have the most impact. To obtain results on optimal location further analysis and calculations have to be done in order to provide an optimal location for the reactive compensation device.

Appendix C

Assessments Methodology – Constraint Management

This appendix describes the methodologies for assessing the potential constraint management benefits.

1.1 Constraint management (operational cost implications) – methodology

This section outlines our methodology, including component tasks, adopted for valuing the ancillary services impact in relation to constraint management.

Task 1: Agree modelling assumptions

National Grid used its in house tool used to prepare long term forecast of constraints costs, namely ELSI. National Grid had agreed with the regulator that analysis undertaken as part of this round of Cap and Floor consultation will utilise the Future Energy Scenarios 2014 and focus on Gone Green scenario (year 2020 as a priority) only.
Other Key input assumptions, relevant to this assessment, which are essential to establish forecasts for constraints and their sources, are outlined below:

- *Details of Interconnector:* these include agreed connection points for each Interconnector (only one per project) and capacity; this information has been sourced from the Customer Account Managers and used consistently across all work streams
- *Interconnector in the background:* the regulator has confirmed to include Eleclink and Nemo in the background; details for these Interconnector will be sourced from FES 2014 or (from the Customer Account Managers, as necessary) and used consistently across all work streams
- *Network capability:* The base network capability for all combinations will be assumed as Year 7 ETYS 2014. Any additional capability resulting from each of the fourteen combinations has been provided by the team evaluating the boundary capability impacts.
- *Value of SO to SO trade actions:* Given the limitation of Interconnector modelling within ELSI, any differences in Interconnector flows between unconstrained and constrained schedules need to be reconciled by using a benchmark value derived from typical values of SO to SO trades and week ahead trading depending on direction of flow and market affected. The relevant benchmark values were sourced from Market Operations, and are outlined in detail in the next section. In addition, the analysis also tests the impact of price sensitivities, namely plus and minus 25%.
- *Price forecasts for interconnected member states:* ELSI already has annual forecasts for 'All Mainland Europe' and 'All Ireland' up to 2030. In order to evaluate the impact of Interconnector offering connections with different market, the forecasts for each market have been sourced through data available in the public domain along with consultation with European System Operators. In addition to the base price assumptions, the analysis also tests the impact of price sensitivities, namely plus and minus 10%. Again details of price assumptions adopted are outlined in the next section of this appendix.

Task 2: Unconstrained Flows and Base Case run

This task is split into three parts:

- *Model set up*: this involves preparing ELSI to undertake constraints forecasts for the 14 combinations outlined above (for GG year 2020 primarily, and year 2030), using the input assumptions captured as part of Task 1.
- *Unconstrained flows*: this involves preparing forecasts of Interconnector flows between GB and interconnected member states, when no network limitations exist. The outputs of these results represent the true market driven flows for Interconnector based on price signals. These will be undertaken for all fourteen combinations.
- *Base case constrained flow:* this involves forecasting the constraint costs in year 2020 (and 2030, if feasible) if none of the new Interconnector projects materialised. It is worth noting that the network capabilities will be set as ETYS 2014 Year 7 limits. This sets the counterfactual case for valuing the benefits of the agreed combinations in terms of constraint management.

Task 3: Constrained runs (including boundary capability)

To progress this task, impact on network capabilities by boundaries for each of the combinations, was made available by the team assessing the impact of boundary capabilities.
This analysis resulted in the following forecasts for each of the fourteen combinations:

- Interconnector flows for all fourteen combinations, if the network limitations existed
- Constraint cost forecasts for each combination, incorporating the network capability benefit delivered by them.

At this stage it is worth noting that, as mentioned in Note 1 issued to the regulator, the HVDC links could be of VSC technology and therefore provision of full reactive power capability, as defined by the Grid Code 0.95 lag and lead, for voltage compliance would be available at any active dispatch. HVDC VSC can contribute to the voltage profile of the local area and therefore the possibility of increasing boundary transfer capability arises (limited to boundaries on MITS that are local to HVDC and constrained by voltage). For the purposes of the boundary capability analysis undertaken by National Grid, and presented in the respective document, it has been assumed that all Interconnector use VSC technologies.

Task 4: Reconcile unconstrained and constrained runs

The true flows associated with an Interconnector are based on the price arbitrage between the two markets. The unconstrained forecasts for flows represent such flows. However, in order to establish the constraint cost implications of a given Interconnector, network capabilities or limitations are required to be introduced. ELSI, a zonal model, subsequently moves away from unconstrained Interconnector flows whilst performing a constrained forecast.
Hence, in order to forecast the 'total' operational cost implication of an Interconnector, the flows for constrained run need to be reconciled with the unconstrained run. Each MWh of reconciliation between constrained and unconstrained runs will be valued at a respective benchmark value

associated with each Interconnector[19]. The benchmark value assumptions are outlined in the next section.
The monetised value of this reconciliation is added to the constraint cost forecast to estimate full operational cost for a particular combination.

Task 5: Impact of each combination

The outputs of Task 4 for each combination will be subtracted from the counterfactual constraint forecasts prepared in Task 2. The impact estimates are presented in terms of present value (2014/15 prices), using a HM Treasury recommended Social Time Preference Rate of 3.5% p.a.
The analysis from task 2 to task 5 will also be undertaken for the price sensitivities (plus and minus 10%) and documented in a report.

Furthermore, the boundary capability envisaged to be delivered by different Interconnector combinations impacts could displace transmission investment. The potential monetised value of this additional incidental capability by different Interconnector combinations is estimated using the unit cost allowances outlined in NGET's Incremental Wider Works (IWW) outputs[20]. Like the operational cost analysis, the impact of displaced capital investment is also presented in terms of present value (2014/15 prices), using a HM Treasury recommended Social Time Preference Rate of 3.5% p.a.

1.3 Limitations of the analysis

The critical mass offered by some of the Interconnector combinations studied as part of the constraint management analysis may displace other investments from the GB market and subsequently impact on generation backgrounds. Such an impact on the backgrounds can have further impacts on various outputs of this analysis. It is worth noting that the analysis undertaken as part of this report does not take into consideration such effects of different combinations of Interconnector on the generation investment forecasts for the GB market.
The price forecasts adopted for interconnected markets have seasonal and daily variation. Despite the variable price forecasts, the modelling undertaken as part of this constraint management analysis does not include any formal considerations for ramping restrictions across periods of a day. Other exclusions from the analysis are:

- Impact of European Codes
- RoCoF costs.

The remainder of this document outlines the price assumptions adopted for the interconnected member states and intermediate outputs regarding projected flows and load factors for the new Interconnector across the combinations appraised. This is followed by presentation of the analysis and conclusions regarding constraint management and investment displaced.

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[19] The benchmark values have been developed from relevant price assumptions for both SO-SO trades and week ahead trading price. Please note that both set of assumptions as well as the derived averages (for reconciliation costs) are based on direction of flow and the envisaged interconnected market.

[20] Source: https://epr.ofgem.gov.uk/Content/Documents/National%20Grid%20Electricity%20Transmission%20Plc%20-%20Special%20Conditions%20-%20Current%20Version.pdf

Price Assumptions and Load Factors

2.1 Introduction

This section outlines the price assumptions adopted for interconnected member states. This includes:

- Historic variability of price during the day and across seasons in different current and future interconnected European member states
- Annual forecast of base load energy prices by interconnected European member states for 2020 and 2030
- Derived price assumptions by interconnected European member states for 2020 and 2030.

Using the outlined price assumptions, the chapter also presents the intermediate modelling outputs in terms of forecast flows and estimated load factors for each of the new proposed Interconnector for the fourteen identified combinations. This analysis is presented for both 2020 and 2030, with Gone Green as the wider network background for GB.

Furthermore, as outlined in Chapter 1, estimation of total operational costs resulting from the introduction of new Interconnector to the generation background requires reconciliation of constrained and unconstrained runs. This reconciliation needs to reflect direction of flow and the market affected. This chapter also outlines the benchmark values adopted these reconciliations.

2.2 Historic Price variability

Modelling within ELSI environment is performed over all 365 days of the year. A year is distributed across three broad seasons, namely summer, spring/autumn and winter. Furthermore, driven by load duration curve, a typical day is distributed across four periods, including peak, plateau, and night trough and pick up / drop off.

Historical data sourced from the public domain suggests that base load energy price in a particular market has seasonal and daily variability. In particular, the graph below demonstrates the price variability[21] in different markets currently interconnected or markets that could be interconnected with GB, if the projects proposed through this Cap and Floor consultation were to be taken forward. The data suggests that as demand changes through the day, the price in a particular market is affected. Furthermore, there appears to be a similar pattern across various European member states over different seasons. The data also demonstrates that there is less price variability in member states on mainland Europe compared to Ireland.

[21] For the purpose of this analysis, price variability curve is defined as price in a particular market during a particular period (and season) as a percentage of the annual average base load energy price.

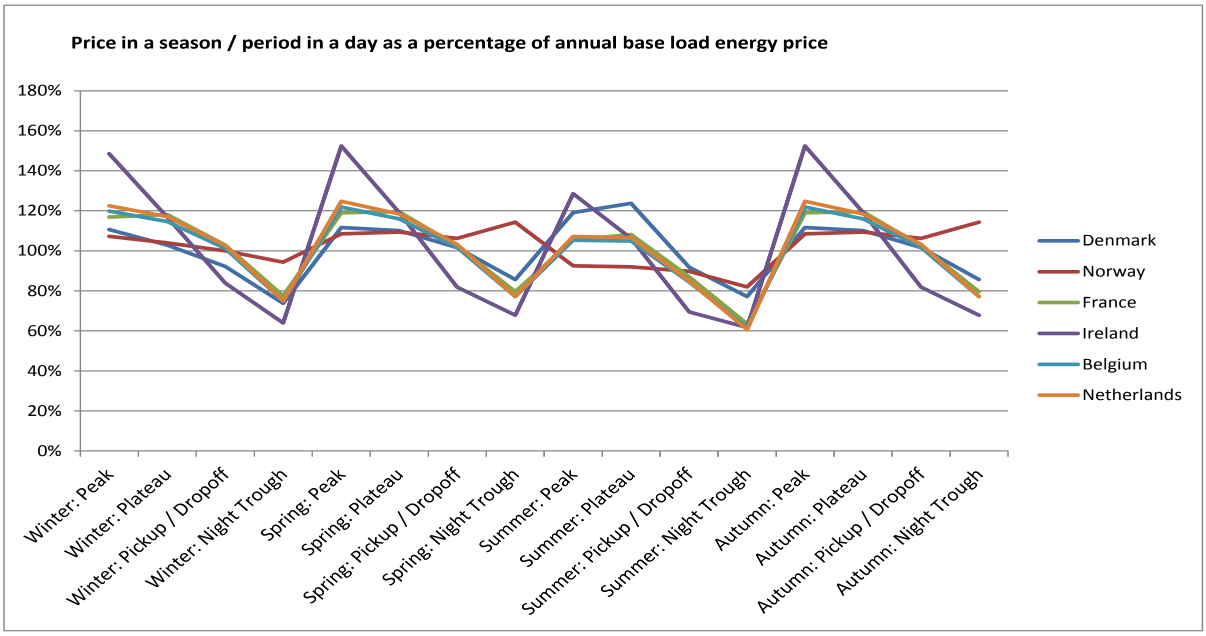

Figure C1: Price variability in different European energy markets

2.3 Annual Price Forecast

Through consultation with various European TSOs, we have developed energy price forecasts for 2020 and 2030 for various member states. These are summarised in the tables below. As the analysis for the GB network is based on Gone Green scenario, it is worth noting that these price forecasts represent a similar vision for considered European markets.

Countries	2020 Base Price Forecast (in £ per MWh)	2020 Base Price plus 10% Forecast (in £ per MWh)	2020 Base Price minus 10% Forecast (in £ per MWh)
Denmark	X	X	X
Norway	X	X	X
France	X	X	X
Ireland	X	X	X
Belgium	X	X	X
Netherlands	X	X	X

Table C1: Annual Base Load Electricity Price Forecasts and Sensitivities for 2020 (in £s per MWh)

Countries	2030 Base Price Forecast (in £ per MWh)	2030 Base Price plus 10% Forecast (in £ per MWh)	2030 Base Price minus10% Forecast (in £ per MWh)
Denmark	[redacted]	[redacted]	[redacted]
Norway	[redacted]	[redacted]	[redacted]
France	[redacted]	[redacted]	[redacted]
Ireland	[redacted]	[redacted]	[redacted]
Belgium	[redacted]	[redacted]	[redacted]
Netherlands	[redacted]	[redacted]	[redacted]

Table C2: Annual Base Load Electricity Price Forecasts and Sensitivities for 2030 (in £s per MWh)

The data presented in the tables above along with the historic seasonal and daily variation for respective markets presented in Figure 1, were amalgamated to develop 2020 and 2030 price forecasts with periodic variation. The base 2020 and 2030 forecasts are outlined in the figures below.

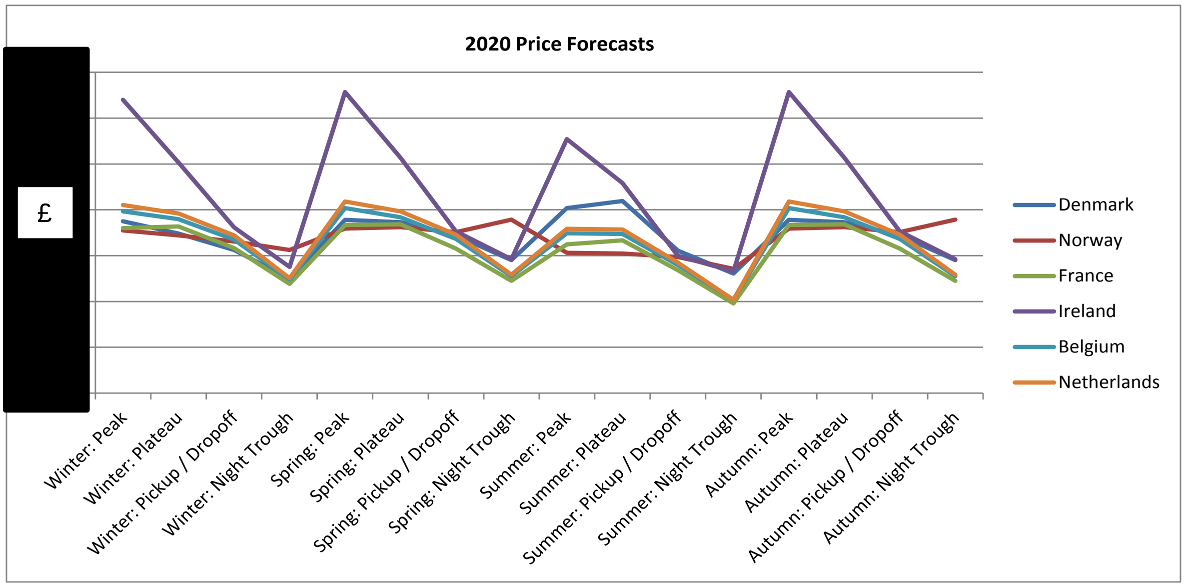

Figure C2: 2020 base price forecasts for different European energy markets (in £s per MWh)

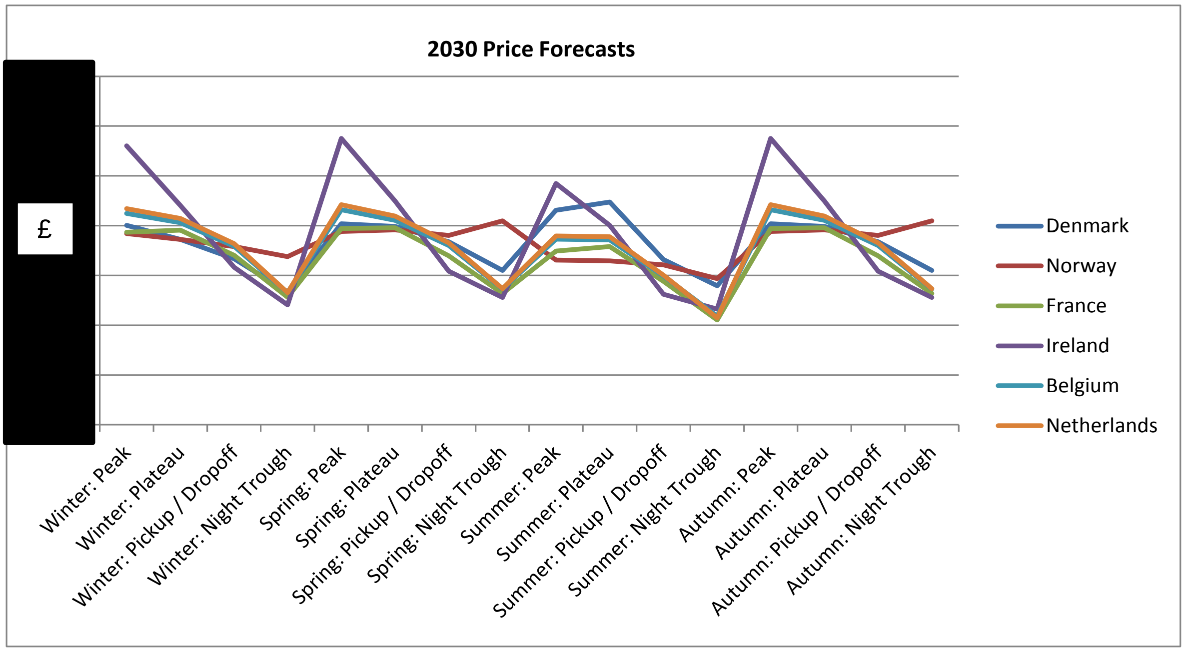

Figure C3: 2030 base price forecasts for different European energy markets (in £s per MWh)

2.4 Forecast Unconstrained Flows and Load Factors

Adopting the 2020 base price forecasts assumptions for different European member states, the 2020 base case unconstrained flows for existing Interconnector was modelled[22]. This was followed by modelling of forecast flows for all fourteen combinations outlined in Chapter 1. The results are summarised in the table below. The results demonstrate that GB will continue to be net importer of power in 2020. Furthermore, flows for Interconnector are projected to increase from a baseline position of approximately 45 TWh with increasing interconnected capability, up to a maximum of approximately 80 TWh in a case if all five Interconnector applying through this round of Cap and Floor support were delivered.

With early signs of price convergence between GB and various European markets by 2030, Interconnector flows for the base case are projected to drop considerably to approximately 15 TWh of net imports. These levels of flows are very similar to current flows on existing Interconnector. The increase in flows with greater level of interconnected capability is forecasted to much less in 2030 compared to 2020. The more closely aligned market prices also result in greater exports from the GB.

[22] As requested by Ofgem, the base case forecasts include Eleclink and Nemo in the background.

Markets/Combinations	Base	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Intercon Netherlands Gen TWh	7.7-7.8	7.6-7.7	7.6	7.8	7.7	7.8	7.4	7.3	7.4-7.5	7.5	7.4-7.5	7.5	7.4-7.5	7.4	7.7
Intercon Netherlands Dem TWh	0-0.1	0-0.1	0-0.1	0-0.1	0-0.1	0-0.1	0.0	0.0	0-0.1	0.0.1	0-0.1	0-0.1	0-0.1	0-0.1	0-0.1
Intercon France Gen TWh	24.2-24.5	32-32.5	35.1-35.6	24.2-24.5	24.2-24.5	24.1-24.4	42.9-43.5	42.7-43.3	42.9-43.6	42.9-43.5	42.8-43.4	43-43.6	42.7-43.3	42.8-43.4	24.1-24.4
Intercon France Dem TWh	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Intercon Denmark Gen TWh	0.0	0.0	0.0	0.0	7.7-7.8	0.0	7.3-7.4	7.2-7.4	7.3-7.4	0.0	0.0	0.0	0.0	7.2-7.4	7.6-7.8
Intercon Denmark Dem TWh	0.0	0.0	0.0	0.0	0-0.1	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0-0.1	0-0.1
Intercon Ireland Gen TWh	3.7-6.6	3.6-6.5	3.5-6.4	6.2-11.2	3.6-6.5	3.7-6.5	5-9.5	3-5.7	5.1-9.8	5.3-10.0	3.3-6.2	5.5-10.3	3.2-6.0	3.1-5.9	3.5-6.4
Intercon Ireland Dem TWh	0.3-1.3	0.4-1.4	0.4-1.4	0.5-2.1	0.4-1.4	0.4-1.4	1.2-2.8	0.8-1.7	0.9-2.6	0.9-2.6	0.5-1.5	0.8-2.5	0.6-1.6	0.5-1.6	0.4-1.4
Intercon Belgium Gen TWh	7.8-7.9	7.7-7.8	7.7	7.9-8	7.8	7.8-7.9	7.5-7.6	7.5-7.6	7.6	7.6-7.7	7.6-7.7	7.6-7.7	7.5-7.6	7.5-7.6	7.8
Intercon Belgium Dem TWh	0-0.1	0.1-0	0-0.1	0-0.1	0-0.1	0.0	0.0	0.0	0.0	0.0	0-0.1	0-0.1	0.0	0.0	0.0
Intercon Norway Gen TWh	0.0	0.0	0.0	0.0	0.0	10.5-10.7	9.6-9.8	9.7-10	0.0	9.8-10.1	0.0	0.0	9.9-10.2	0.0	10.2-10.5
Intercon Norway Dem TWh	0.0	0.0	0.0	0.0	0.0	-0.5	0.8-1.1	0.8-1.0	0.0	0.7-0.9	0.0	0.0	0.7-0.9	0.0	0.5-0.6

Table C5: 2020 forecast flows for Interconnector across all considered combinations (base price forecasts and sensitivities)

Markets/Combinations	Base	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Intercon Netherlands Gen TWh	4.3-4.6	4.0-4.4	3.9-4.3	4.2-4.6	4.2-4.6	4.1-4.6	3.1-3.8	3.2-3.8	3.3-3.9	3.2-3.9	3.4-4.1	3.5-4.1	3.3-3.9	3.3-4.0	4.0-4.5
Intercon Netherlands Dem TWh	2.3-2.7	2.3-2.7	2.3-2.6	2.2-2.6	2.2-2.6	2.2-2.6	2.0-2.4	2.1-2.5	2.1-2.5	2.1-2.5	2.3-2.7	2.2-2.6	2.2-2.6	2.2-2.6	2.1-2.5
Intercon France Gen TWh	14.9-15.4	19.4-20.2	21.1-22	14.8-15.4	14.9-15.5	14.6-15.3	24.8-26.1	25-26.3	25.2-26.3	24.7-26.1	25.3-26.5	25.1-26.3	24.8-26.2	25.4-26.5	14.7-15.3
Intercon France Dem TWh	5.6-6.8	7.2-8.7	7.7-9.5	5.4-6.6	5.2-6.4	5.2-6.5	7.6-9.5	7.9-9.8	8.1-10.1	8.2-10.1	9.0-11.2	8.7-10.9	8.5-10.2	8.4-10.4	4.8-6.0
Intercon Denmark Gen TWh	0.0	0.0	0.0	0.0	3.9-4.3	0.0	3.1-3.5	3.1-3.6	3.2-3.5	0.0	0.0	0.0	0.0	3.3-3.6	3.8-4.8
Intercon Denmark Dem TWh	0.0	0.0	0.0	0.0	2.3-2.7	0.0	2.2-2.7	2.2-2.8	2.3-2.7	0.0	0.0	0.0	0.0	2.3-2.8	2.6-4.1
Intercon Ireland Gen TWh	3.8-4.6	3.6-4.4	3.5-4.2	6.4-7.6	3.7-4.4	3.7-4.4	5.2-6.2	3.1-3.6	5.3-6.4	5.4-6.5	3.4-4.0	5.6-6.7	3.2-3.9	3.2-3.9	2.2-3.5
Intercon Ireland Dem TWh	2.5-2.8	2.5-2.9	2.5-2.9	4.1-4.7	2.4-2.8	2.5-2.9	4.3-4.8	2.2-2.9	4.3-4.8	4.3-4.9	2.6-3.0	4.3-4.9	2.6-3.0	2.6-2.9	2.5-2.9
Intercon Belgium Gen TWh	4.5-4.6	4.2-4.4	4.1-4.2	4.4-4.7	4.4-4.7	4.3-4.7	3.4-4.0	3.4-4.0	3.6-4.1	3.5-4.2	3.7-4.2	3.7-4.2	3.5-4.2	3.6-4.2	4.2-4.7
Intercon Belgium Dem TWh	2.5-2.6	2.2-2.5	2.2-2.5	2.1-2.5	2.1-2.5	2.1-2.5	1.9-2.3	2.0-2.4	2.0-2.4	2.0-2.4	2.2-2.5	2.1-2.5	2.1-2.5	2.1-2.5	2.0-2.4
Intercon Norway Gen TWh	0.0	0.0	0.0	0.0	0.0	5.7-6.3	5.2-5.7	5.2-5.8	0.0	5.3-5.8	0.0	0.0	5.3-5.9	0.0	5.5-6.2
Intercon Norway Dem TWh	0.0	0.0	0.0	0.0	0.0	4.4-4.0	3.5-4.1	3.5-4.1	0.0	3.5-4.1	0.0	0.0	3.4-4.0	0.0	3.4-4.0

Table C6: 2030 central forecast flows for Interconnector across all considered combinations (base price forecasts and sensitivities)

Key:

1. IFA2 Only
2. FAB Only
3. Greenlink Only
4. Viking Link Only
5. NSN Only
6. All five projects together
7. All projects minus Greenlink
8. All projects minus NSN
9. All projects minus Viking Link
10. Both French Interconnectors only
11. Both French and Greenlink only
12. Both French and NSN only
13. Both French and Viking Link only
14. Both Viking Link and NSN only

This analysis demonstrates that flows on the Irish Interconnector are much more sensitive price changes, compared to member states from mainland Europe.

The forecast flows along with respective capacities were adopted to derive the load factors for new Interconnector across all fourteen combinations considered as part of this analysis. The results are presented in the tables below.

Markets/ Combinations	Flow direction	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Intercon France	GB import	89-91%	89-91%				89-90%	88-89%	89-91%	89-90%	89-90%	89-91%	88-89%	88-90%	
Intercon France	GB export	0%	0%				0%	0%	0%	0%	0%	0%	0%	0%	
Intercon Denmark	GB import				88-89%		83-85%	83-84%	83-85%					83-84%	87-89%
Intercon Denmark	GB export				1%		1%	1%	1-2%					1-2%	1%
Intercon Ireland	GB import			41-70%			21-47%		22-52%	27-47%		28-64%			
Intercon Ireland	GB export			3-14%			14-24%		9-21%	10-21%		7-21%			
Intercon Norway	GB import					85-87%	78-80%	79-81%		81-82%			81-83%		83-86%
Intercon Norway	GB export					4%	7-9%	6-8%		6-7%			5-7%		4-5%

Table C7: Central 2020 forecast load factors for new Interconnector across all considered combinations (base price forecasts and sensitivities)

Markets/ Combinations	Flow direction	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Intercon France	GB import	52-54%	52-54%				47-51%	48-52%	49-52%	47-51%	49-52%	49-52%	47-51%	50-53%	
Intercon France	GB export	18-22%	17-22%				9-13%	11-14%	12-16%	12-16%	16-21%	15-19%	14-18%	13-17%	
Intercon Denmark	GB import				45-49%		35-40%	36-41%	37-40%					38-41%	45-47%
Intercon Denmark	GB export				26-31%		25-31%	26-32%	26-31%					26-32%	25-30%
Intercon Ireland	GB import			46-49%			22-26%		24-30%	25-31%		28-35%			
Intercon Ireland	GB export			26-31%			30-33%		29-33%	30-34%		29-34%			
Intercon Norway	GB import					46-52%	42-46%	43-47%		43-47%			43-48%		45-51%
Intercon Norway	GB export					28-32%	29-33%	28-33%		28-33%			28-33%		27-32%

Table C8: 2030 forecast load factors for new Interconnector across all considered combinations (base price forecasts and sensitivities)

Key:

1. IFA2 Only
2. FAB Only
3. Greenlink Only
4. Viking Link Only
5. NSN Only
6. All five projects together
7. All projects minus Greenlink
8. All projects minus NSN
9. All projects minus Viking Link
10. Both French Interconnectors only
11. Both French and Greenlink only
12. Both French and NSN only
13. Both French and Viking Link only
14. Both Viking Link and NSN only

Key observations from the above analysis are summarised below.

In particular, in 2020, the load factors for the new French, Danish and Norwegian Interconnector remains very high and varies marginally across all combinations considered. However, amongst these new Interconnector with markets in mainland Europe, the NSN Interconnector is forecasted to have the greatest level of exports, as a proportion of its capacity, from GB. In comparison the new Greenlink Interconnector achieves a lower load factor. Furthermore, exports from GB as a proportion of the new Interconnector's capacity are forecasted to be the greatest on the Greenlink link. It is also worth noting that as GB's interconnectivity with mainland Europe increase, exports from GB, particularly to Ireland expand.

In 2030, the load factors for the new French, Viking Link and NSN Interconnector are not only forecasted to reduce but they are also expected to vary more across all combinations considered compared to 2020. Furthermore, all markets in mainland Europe see a notable increase in exports from GB. The new Greenlink Interconnector achieves an even lower load factor, with exports from GB accounting for a greater proportion of the link's utilisation.

2.5 Reconciliation Costs

The benchmark values for reconciliations have been developed as averages of relevant price assumptions for both SO-SO trades and week ahead trading price outlined in the Tables C7 and C8 respectively. Please note that both set of assumptions and these average reconciliation costs, summarised in Table C9 are based on direction of flow and the envisaged interconnected market affected.

Countries	SO to SO Trade Costs (in £ per MWh): Curtailing GB imports	SO to SO Trade Costs (in £ per MWh): Curtailing Europe imports
Denmark	[redacted]	[redacted]
Norway	[redacted]	[redacted]
France	[redacted]	[redacted]
Ireland	[redacted]	[redacted]
Belgium	[redacted]	[redacted]
Netherlands	[redacted]	[redacted]

Table C9: Assumption for SO to SO trade costs by market.

Countries	Average Cost of Week Ahead Trade (in £ per MWh): Curtailing GB imports	Average Cost of Week Ahead Trades (in £ per MWh): Curtailing Europe imports
Denmark	[redacted]	[redacted]
Norway	[redacted]	[redacted]
France	[redacted]	[redacted]
Ireland	[redacted]	[redacted]
Belgium	[redacted]	[redacted]
Netherlands	[redacted]	[redacted]

Table C10: Assumption for week ahead trade costs by market

Countries	Average costs of Trades (in £ per MWh): Curtailing GB imports	Average costs of Trades (in £ per MWh): Curtailing Europe imports
Denmark	[redacted]	[redacted]
Norway	[redacted]	[redacted]
France	[redacted]	[redacted]
Ireland	[redacted]	[redacted]
Belgium	[redacted]	[redacted]
Netherlands	[redacted]	[redacted]

Table C11: Central assumption for average reconciliation costs by market

Sensitivities regarding the above derived central assumptions for reconciliation costs by market have also been considered as part of this analysis. These are outlined in the tables below.

Countries (Central assumptions plus 25%)	Average costs of Trades (in £ per MWh): Curtailing GB imports	Average costs of Trades (in £ per MWh): Curtailing Europe imports
Denmark	[redacted]	[redacted]
Norway	[redacted]	[redacted]
France	[redacted]	[redacted]
Ireland	[redacted]	[redacted]
Belgium	[redacted]	[redacted]
Netherlands	[redacted]	[redacted]

Table C12: Average reconciliation costs by market: increased cost sensitivity

Countries (Central assumptions minus 25%)	Average costs of Trades (in £ per MWh): Curtailing GB imports	Average costs of Trades (in £ per MWh): Curtailing Europe imports
Denmark	[redacted]	[redacted]
Norway	[redacted]	[redacted]
France	[redacted]	[redacted]
Ireland	[redacted]	[redacted]
Belgium	[redacted]	[redacted]
Netherlands	[redacted]	[redacted]

Table C13: Average reconciliation costs by market: reduced cost sensitivity