nationalgrid

Network Options Assessment for Interconnectors

Interconnectors Welfare Benefit Assessment Methodology

July 2017

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About this document

This document contains National Grid's Network Options Assessment (NOA) methodology for assessment of interconnectors established under NGET Licence, Licence Condition C27 in respect of the financial year 2017/18. It covers the methodology on which NGET in its role as SO will base the third NOA for Interconnectors report which will be published by 31 January 2018 as a chapter of the NOA report. National Grid's experience and stakeholder feedback has informed the development of this methodology. The methodology statement has been revised for the third NOA for Interconnectors and will continue to be on an enduring basis as required by Licence Condition C27.

Contents

1. Overview

The purpose of the Network Options Assessment (NOA) is to facilitate the development of an efficient, coordinated and economical system of electricity transmission consistent with the National Electricity Transmission System Security and Quality of Supply Standard (NETS SQSS) and the development of efficient interconnector capacity. Interconnectors with other European markets will increasingly play an important role to achieve this goal.

This document provides an overview of the aims of the NOA with respect to interconnectors and details the methodology which the System Operator (SO) will adopt for the analysis and publication of the third NOA report (to be published by 31st January 2018). The SO shall undertake further enhanced analysis for NOA for Interconnector 2017 taking into consideration locational impacts in addition to the welfare and capital cost implications which were considered last year.

1.1. Structure of the Document

This document consists of the 7 chapters listed below:

Factors for the assessment of future interconnection

This chapter contains a justification of the factors to be considered in the determining whether additional capacity would be beneficial.

Cost estimation for interconnection capacity

The costs associated with an interconnector and how these will be forecast.

Cost estimation for network reinforcement

The costs associated with network reinforcements and how these will be forecast.

Components of Welfare Benefits of Interconnectors

This section outlines the concept of Socio-Economic Welfare in relation to interconnection and how the components of the calculation.

Constraint cost implications

An outline of how interconnectors could impact the operational costs on the network.

BID3 model

A description of the SO’s current market modelling capabilities

Interconnection Assessment Methodology

A description of the method by which the SO proposes to meet the aims of NOA in relation to optimal interconnection capacity is provided.

2. Factors for the assessment of future interconnection

There are multiple factors which could be considered when evaluating interconnector projects. The foremost are Social Economic Welfare, capital costs and impact on constraint costs. Constraint costs refer to GB network congestion costs borne by GB consumers as a result of interconnection.

Two factors that will be analysed and have some accompanying commentary in the NOA report are changes in carbon emissions and use of Renewable Energy Sources (RES). These indicators are intended to aid understanding of interconnection's potential contribution or detriment to meeting GBs climate change goals. They will not be used to optimise the interconnection presented. This is due to the complexity of combining Carbon/RES estimates with welfare and cost, especially where modelled welfare is already influenced by such factors through RES incentives and the European Trading System capping carbon emissions.

- **Carbon costs**: modelling facilities allow for the extraction of total carbon emissions resulting from particular market states under different scenarios, thus the carbon savings or increases associated with various levels of interconnection can be presented with commentary. The interaction of emissions and welfare with the European Trading System in carbon may reduce the apparent impact of interconnection directly on emissions; further analysis and commentary in the report should explain this effect.

- **RES integration**: modelling facilities (as described in section 7) allow for the investigation of impact of interconnection on renewable generation. This can be reviewed through investigating the reduction or increase in renewable generation curtailment driven by the optimal level of interconnection being in place in future years, rather than the currently forecast level.

There are further benefits and costs that could be considered, which are briefly outlined below; they are outside the scope of this methodology:

- **Operational costs**: Various costs associated with the day-to-day operation of the interconnector, and the maintenance of its components, are omitted from the analysis. This is driven by the complexity of defining these costs, per market, for little to no potential improvement in the solution. There is a high correlation between capital spend (which is included) and these operational costs. Moreover, there is unlikely to be a substantial variation in the 'standard' operational costs per European market under consideration, meaning it is equitable to remove them from consideration for all markets. One may argue that the operational costs may cause the end of the optimal path to be reached sooner however a decision has been made to omit this factor from the analysis due to the insignificance in relation to SEW over 25 years.

- **Environmental/social costs**: In any large scale construction project, the local environment may potentially suffer damage. This affects local stakeholders, as well as disruption associated with the construction (traffic, noise etc.). The severity varies with the site chosen and the construction methods used. These are not considered here as they are more relevant to the choice of sites for individual projects.

- **Social benefits**: Depending upon the procurement for the construction, the project may offer a boom to the local economy. This again is a project specific benefit, so is not estimated in this work.

- **Ancillary service benefits**: A major consideration is the ability of interconnectors to provide services which enhance system operability. This could potentially benefit both the interconnector owner, with additional income streams, and the consumer, by increasing system security or lowering the cost of providing system security. This is evaluated on a project-by-project basis as part of the Cap and Floor mechanism, so again is excluded here. More information on ancillary service provision, and interconnectors' potential contribution to this, is available in the System Operability Framework (SOF) and Cap and Floor W2 report.[1]

SEW, CAPEX and Attributable Constraint Costs (ACC) are the most significant criteria for identifying the optimal level of interconnection. Therefore these factors will be used in the analysis to determine the economically optimal level of interconnection.

[1] The Cap and Floor report: https://www.ofgem.gov.uk/system/files/docs/2017/06/nget_report_to_ofgem_-_quantified_interconnector_impacts.pdf

3. CAPEX estimation for Interconnection

The cost of building interconnection capacity varies significantly between different projects - key drivers are convertor technology, cable length and capacity of cable. Estimating costs for generic interconnectors between European markets and GB is therefore challenging. Fortunately, an exercise of a similar nature has been undertaken by various industry bodies to allow the generation of 'Standard Costs'. These are generic values that can be applied to estimate the cost of generic projects. A report by ACER [2]provides sufficient granularity to differentiate between standard costs of connection to different markets. There are 3 elements to the capital costs; subsea cable, onshore connection costs and wider reinforcement costs.

- Subsea cable costs will be identified by estimating the furthest and shortest realistic subsea cable length and taking the average distance for each market to GB zone permutation. Suitable substations have been identified using the ENTSO-E Transmission System Map. For each market and GB zone, only logical substations which are neighbouring or have sufficient infrastructure will be reviewed in the study of route length. The length of the cable will vary with the GB zone it is connecting to and the measurements will be taken between these to the nearest 5km and are shown in the table below.

Table 1: Route distances

Country	GB Zone	Distance (Km)
Norway	1	705
Norway	2	795
France	5	175
France	6	100
Netherlands	4	215
Netherlands	6	210
Denmark	4	620
Denmark	7	660
Ireland	2	220
Ireland	3	220
Germany	4	520
Germany	7	590
Belgium	4	185
Belgium	6	140
Spain	5	810

- Onshore connection costs will be included and dependant on distance from the coast to substation locations. Onshore works will be assumed as 80% double circuit 400kV overhead lines and 20% underground cables. This percentage is based on a range of GB reinforcements which may be built in the future.

[2] http://www.acer.europa.eu/Official_documents/Acts_of_the_Agency/Publication/UIC%20Report%20%20-%20Electricity%20infrastructure.pdf

- Wider reinforcement costs will be included in capital costs for options where applicable. (See Chapter 4)

The convertor station assumed value is drawn from an averaging of known HVDC projects performed by ACER. The ACER cost estimates are shown in the table below:

Table 2 Standard costs

Total cost per route length (km)	Rating	Mean (€, 2014)
DC cables*	250-500kV	757,621
OHL**	380-400kV (2 circuits)	1,060,919
Underground cables**	380-400kV (2 circuits)	4,905,681

Total cost per rating (MVA)	Mean (€, 2014)
HVDC convertor station	87,173

These costs include the cost of installation.

* The DC cable cost provided is for a 500MW cable. An assumption has been made that for a 1000MW interconnector the cost per km will be double.

** The rating on the figures above is sufficient to accommodate an additional 2000MW of interconnection. Therefore, the figures will be adjusted to incur 70% of the total cost for the first 1000MW of capacity required and 30% for the second 1000MW of reinforcement capacity on the same boundary.

At the start of the analysis, the suitable rate of conversion from 2014 euros to present day sterling will be drawn from a credible source available to the SO (Bloomberg). The table can then be used to generate a generic cost for a given increase in capacity for each market. As connection can occur across a range of years, discounting is employed to standardise each cost in Present Value. This is done with the Social Time Preference Rate (STPR) of 3.5%. Additionally, the cost of capital is taken account of through the use of a Weighted Average Cost of Capital (WACC) of 6.8% for Interconnectors, drawn from a publically available Grant Thornton report.[3]

An explanation of how WACC and discount rates are used by the SO to obtain a Present Value is in Appendix 1, which describes how Spackman analysis is employed.

[3] https://www.ofgem.gov.uk/ofgem-publications/51476/grant-thornton-interest-during-construction-offshore-transmission-assets.pdf

4. CAPEX estimation for network reinforcements

The network has been divided into seven high level zones which have been determined by areas of significant constraints on the network or areas of high interconnection as illustrated in Figure 1.

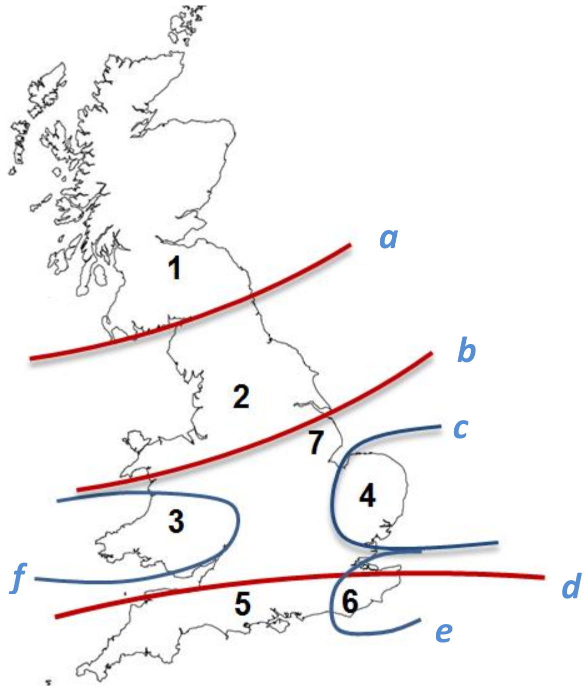

Figure 1: Illustration of Network Zones

As NOA 3 will not be complete before the start of the analysis, a fair representation of baseline boundary capabilities will be determined using the output of NOA 2. Further detail regarding specific baseline reinforcements can be found in the NOA document[4] which outlines the reinforcement background and how it varies across the scenarios.

Generic reinforcements will be created for each boundary, using ACER costs as a guide. (see Table 2). This will provide an indication of where there are high levels of congestion on the network and an indication of the level of reinforcements required.

[4] www.nationalgrid.com/noa

5. Components of Welfare Benefits of Interconnectors

5.1. Introduction

This section outlines the definition of Social Economic Welfare. The purpose of this section is to give the theoretical background of assessing the impact of connected importing and exporting markets on consumers, producers and interconnectors triggered by another interconnector.

5.2. Social and Economic Welfare

Social and Economic Welfare (SEW) is a common indicator used in cost benefit analysis of projects of public interest. It captures the overall benefit, in monetary terms, to society from a given course of action. It is important to understand it is an aggregate of different parties' benefits - so some groups within society may lose money as a result of the option taken. The society considered may be a single nation, GB, or the wider European society, in which case the benefits to European consumers and producers would be a part of the calculation. For the case of GB interconnectors, it is most informative to show both GB and Europe wide SEW values, and the components which make up each. Europe wide SEW is the optimised value in the NOA for Interconnectors.

SEW benefits of an interconnector includes the following three components:

a) Consumer surplus, derived as an impact of market prices seen by the electricity consumers

b) Producer surplus, derived as an the impact of market prices seen by the electricity producers

c) Interconnector revenue or congestion rents, derived as the impact on revenues of interconnectors between different markets.

Interconnectors could help to provide ancillary services (including black start capability, frequency response or reserve response), facilitate deployment of renewables, reduction in carbon emissions and displace network reinforcements. Interconnectors also provide benefits of being connected to more networks giving access to a more diverse range of generation which could lead to reduction in carbon emissions. Such benefits will not be a part of the NOA for Interconnectors assessment, as discussed in the previous section.

5.3. Effects on Interconnected Markets

Power flow between two connected markets is driven by price differentials. Figure 2 shows the effects of such price differentials for two markets, A and B with variable prices over time. When the price is higher in market A, power will be transferred from B to A. When the price in A is lower than B power will be transferred from A to B.

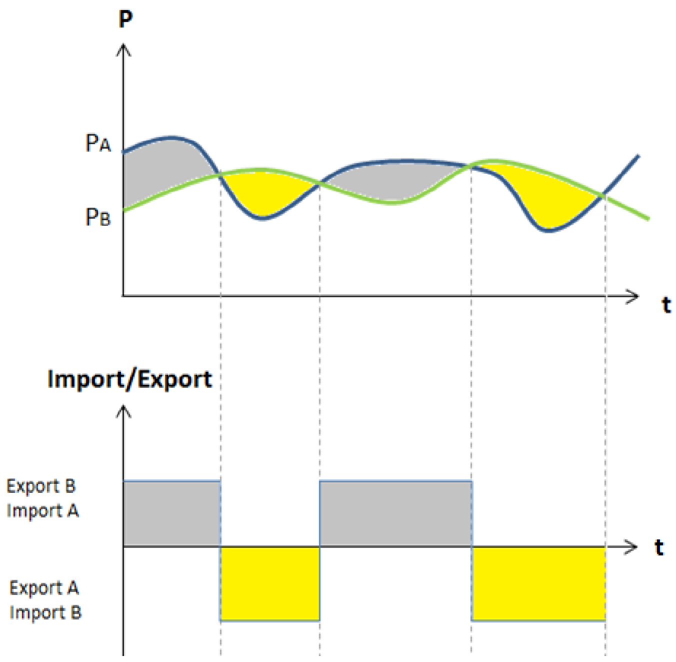

Figure 2 Price difference as import and export driver

Figure 3 shows the impact of an interconnector (+IC) linking two markets on consumer (Demand D) and producer (Supply S) costs. When two competitive markets with different price profiles are interconnected, price arbitrage drives power flow from the low price market (B) to the high price market (A). Consumers in market A are likely to gain (a + b) as they benefit from access to cheaper power. Consumers in market B are likely to lose (d). Generators in market A must now also compete with generators in B and are likely to be forced by competitive pressures to reduce their costs. This may lead to a reduction in their profits (a). Producers in market B are likely to gain (d + e). Interconnector revenue (c) is derived from the remaining price difference.

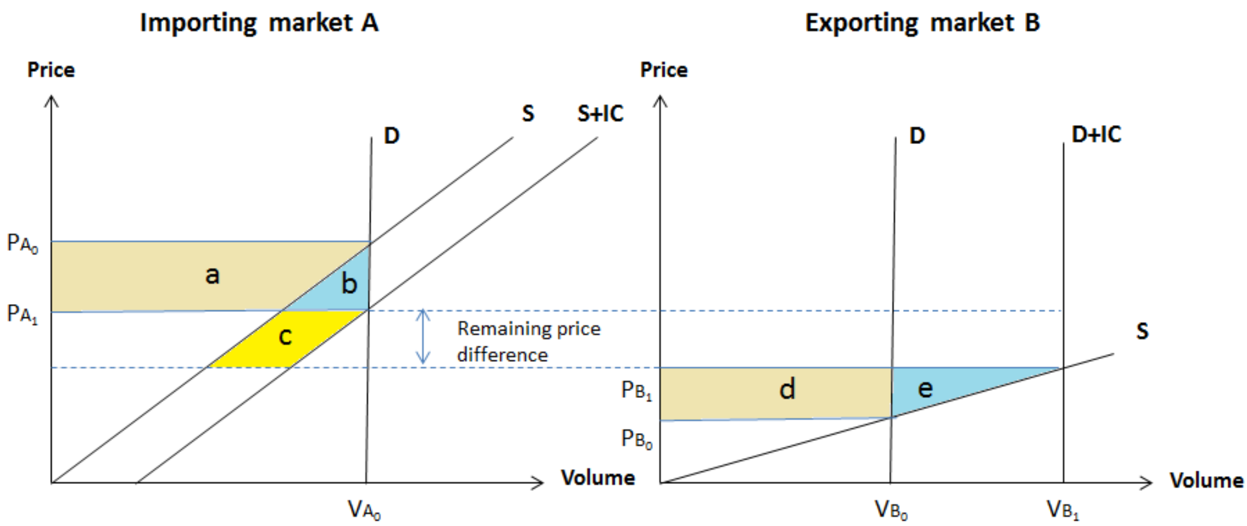

Figure 3 Consumer and Producer Surplus of connected markets

With greater interconnection the price difference between markets will decrease thus the revenue of the interconnector will be reduced as well. This phenomenon is known as ‘cannibalisation’. There is an optimal level of interconnection between any two markets because price differential reduces as capacity increases, i.e. area c in Figure 2 shrinks.

Forecasts of all components of SEW benefits will be key drivers to ascertain the optimum level of interconnection between GB and other European member states. The outputs of this process will include monetised impacts on consumers, producers and considered interconnectors.

The Global SEW is the sum of the welfare of 5 parties (GB consumers, Europe consumers, GB producers, Europe producers and Interconnector owners). The British SEW is the sum of the welfare of all British parties. Using the ownership structure of existing GB interconnectors, assuming 50% of interconnector owner welfare remains in the GB economy is plausible.

Where the market is modelled with and without some additional interconnection capacity added, Socio-Economic Welfare is modelled in each year of a generic asset’s lifetime (25 years is the standard assumption used here). As connection can occur across a range of years, discounting is employed to standardise each year’s benefit in Present Value, also allowing comparison with the discounted capital spend. This is done with the Social Time Preference Rate of 3.5%.

6. Constraint cost implications of interconnection

The impact on constraint costs is dependent on the location of the interconnector on the GB network and the level of onshore reinforcement built to accommodate the interconnector. To enhance the methodology, further detail regarding optimal locations to connect will be output based upon the constraint costs calculated on the network with the interconnectors under consideration.

Constraint costs are incurred on the network when power within the merit order is limited from outputting due to network restrictions. In this event, the System Operator will incur balancing mechanism costs to turn down the generation which is not able to output and offer on generation elsewhere on the system to alleviate the constraint.

The output of the ETYS and NOA reports provides information on the current state and ongoing developments of the onshore network. This will be used to provide a general picture of the optimal network areas for accommodating interconnectors from certain countries. This will be based on constraint costs attributable to the interconnector under review. ETYS and NOA quantify the boundary limitations and present recommended options for reinforcement of the grid. This is intrinsically linked to the increasing presence of interconnection in the UK which can cause further strain on boundaries and potentially trigger investment in further reinforcements if the NOA process determines that to be the most economic and efficient course of action.

Due to timing issues, the output of NOA 2017 will not be available for the assessments for the NOA for interconnectors. However, using the reinforcement options submitted previously and ACER costings, it will be possible to provide indicative, generic reinforcement capacities and investment costs to incorporate in the assessment.

7. BID3 Model

BID3 is the tool which will be used to perform the NOA for Interconnectors 2017 and employed by the System Operator to carry out a range of economic analysis.

BID3 is a Pan European Market Model created by Pöyry. BID3 will be used by National Grid to forecast the Socio-Economic Welfare (SEW) and the Attributable Constraint Costs (ACC).

A comprehensive guide to how National Grid uses BID3 for calculating constraints is available on our website[5].It is an economic dispatch model which can simulate all ENTSO-E power markets simultaneously from the bottom up i.e. it can model individual power stations for example. It includes demand, supply and infrastructure and balances supply and demand on an hourly basis. BID3 models the hourly generation of power stations on the system, taking into account fuel prices, historical weather patterns, socio-economic welfare and operational constraints.

The GB electricity system in BID3 is represented by a series of zones that are separated by boundaries. Generators are allocated to their relevant zone based on where they are located on the network, and then the appropriate demand is allocated to that zone. The boundaries, which represent the actual transmission circuits facilitating the zonal connectivity, have a maximum capability that restricts the amount of power which can be securely transferred to across them.

The socio-economic welfare is calculated by summing the producer surplus, consumer surplus and interconnector revenue. The consumer surplus is the difference between the value of lost load and the wholesale price. The producer surplus is calculated and summed per plant based upon their Short Run Marginal Cost and the wholesale price.

Case collections are used for hourly generation and demand profiles as well as solar and wind profiles. An extensive study has identified the average historic year in terms of Generation, Demand, Wind output, Solar Output, interconnector flows and hydrological year. This is an approved approach but has limitations and could potentially undervalue countries with a high level of renewable generation such as Nordic countries with significant levels of hydro power.

[5] http://www2.nationalgrid.com/LTMNCMBID3/

8. Options included in the assessment

As there are infinite combinations of markets and reinforcements, applying engineering judgement, the number of options has been reduced to 29 credible options. These 29 options will be assessed in all iterations across all four scenarios.

The options which will be assessed are included in Table 3 below. The boundary reinforcements and zones refer to Figure 1.

Market and Zone	Boundary Reinforcements	Market and Zone	Boundary Reinforcements
Belgium Zone 4	c	**Ireland Zone 2**	b
Belgium Zone 4	None	**Ireland Zone 2**	None
Belgium Zone 6	None	**Ireland Zone 3**	None
Belgium Zone 6	d + e	**Netherlands Zone 4**	c
Denmark Zone 4	c	**Netherlands Zone 4**	None
Denmark Zone 4	None	**Netherlands Zone 6**	None
Denmark Zone 7	None	**Netherlands Zone 6**	d + e
France Zone 5	None	**Norway Zone 1**	a + b
France Zone 5	d	**Norway Zone 1**	None
France Zone 6	None	**Norway Zone 2**	b
France Zone 6	d + e	**Norway Zone 2**	None
France Zone 6	d	**Spain Zone 5**	None
Germany Zone 4	c	**Spain Zone 5**	d
Germany Zone 4	None		
Germany Zone 4	f		
Germany Zone 7	None		

Table 3: Options to be considered in the analysis

9. Interconnection Assessment Methodology

9.1. Optimisation of GB-Europe Interconnection Process

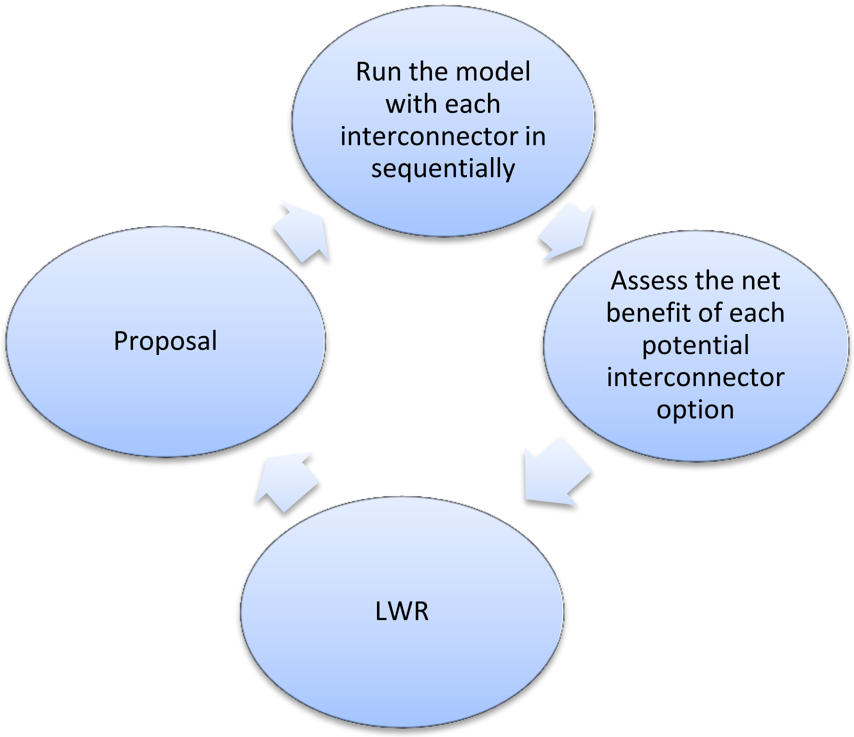

Figure 4 Process summary

The optimisation of future interconnection capacities is a multivariable search, maximising the SEW less CAPEX less Attributable Constraint Costs (ACC) value. The decision variables are the total MW capacities (the sum of all interconnector transfer capacities) between GB and 8 adjacent markets, for both importing and exporting. These markets are national electricity markets- there is some level of coupling between many of them, however price areas (areas with the same electricity price throughout) generally align with nations. Where some nations have multiple price areas, such as Norway, interconnector projects will be assumed to be in the coastal price area deemed most likely for interconnection to the UK (NO5 for Norway). The countries in question are: Norway; Denmark; Germany; The Netherlands; Belgium; France; Spain; and Ireland (which includes the Republic of Ireland and Northern Ireland). For each country's additional interconnector capacity, there will be a small number of zones and reinforcement combinations studied. The number of variables makes an exhaustive search within a useful timeframe infeasible - a search strategy must therefore be defined.

Due to the unique properties of the Icelandic market, any interconnection to Iceland which appears in the Future Energy Scenarios (FES) will remain in the background. Further Icelandic interconnection will be removed from the iterative process.

The search is just for interconnection to the UK. The level of interconnection between European markets will remain fixed throughout the scenarios (though could vary across future years). It is initially defined by the central European scenario procured from Pöyry.

The market studies, which model the physical limitations of transmission between markets (but not within markets) start from the future levels of interconnection that will arise from commissioned links, and future projects with a high degree of regulatory certainty; Eleclink and interconnectors with the Cap and Floor regime; NEMO, IFA2, FAB Link, NSN, Viking, Greenlink, Gridlink, Neuconnect, North Connect. The interconnection capacities are then adjusted sequentially to search for improvements on this initial point, represented by an increase in the global SEW - CAPEX - ACC following the alteration of the capacity values. This global SEW-CAPEX-ACC value takes into account the whole asset life, such that the overall timing of connection is assessed in addition to the capacities per market.

9.2. Modelling inputs

The starting point of the process is National Grid's FES 2017 which includes generation plant ranking orders and demand forecasts for each scenario. FES are focussed on the GB market, however there will be additional development work in BID3 to align the assumptions in the European markets to those of each FES. Output from NOA 2[6] will be used to determine the high level boundary capacities which form the 7 zones included in the analysis. All interconnectors which are in the NOA IC baseline will be included in the model from 2025 (the first year of study).

The FES make forecasts of the future interconnection capacities in GB, per scenario. The FES level of interconnection is calculated on a project by project basis, reviewing all axioms from economic, political, environmental etc. An important distinction between the FES and this process, therefore, is that the NOA for Interconnectors aims to find what would be economically optimal rather than based on specific projects. As a result, interconnectors included in the FES which are not deemed to have a high degree of regulatory certainty (such as the Cap and Floor regime) will be removed from the scenario. A shortfall of capacity will then drive further interconnection in the results.

The time period considered in the studies extends from the present to 2037. This is to match the FES, which forecasts up to 2037 in detail. For the timing analysis, only capacity in years 2025, 2027 and 2030 will be investigated. The reason for not starting to analyse additional capacity until 2025 is this is deemed the earliest an entirely new interconnector project could realistically be connected. Studying every year thereafter is infeasible, as each additional year studied requires a further set of model runs in the optimisation. This would lead to an unachievable number of required runs as constrained by time limitations.

9.3. Market Modelling

The selected method of arriving at a recommendation for capacity development is an iterative optimisation per scenario. The iterative optimisation approach attempts to maximise present value, equal to SEW less CAPEX less Attributable Constraint Costs (ACC), using a search strategy. The whole process is repeated four times to arrive at an optimal development of capacity in each of the four FES. A Least Worst Regret calculation will be used at each iterative step in order to determine 1 optimal path across all FES. A balance between computing resource and rigour in each step of the process must be found. An example step is outlined below, wherein multiple capacity changes are evaluated for SEW in

[6] www.nationalgrid.com/noa

each step, and that capacity change which yields the least worst regret will be added to the baseline for iteration 2.

Timing of capacity increases can affect the SEW generated and Attributable Constraint Costs (ACC) by the interconnection across the study window. Within each search step, therefore, timing combinations will be considered. The use of spot years will be necessary to allow a solution to converge, wherein the commissioning of additional projects would be evaluated only in future years 2025, 2027 and 2030. This means for each iteration, the welfare of the interconnectors in every spot year will be calculated.

The example below is based on a hypothetical situation, optimising the capacities and optimal timing of connection for potential interconnection to 3 markets. The table below does not show the inspection of different years of commission for clarity or the 4 scenarios which would be studied or the additional lines to factor in the capital assumptions, in reality there would be many more options per iterative step.

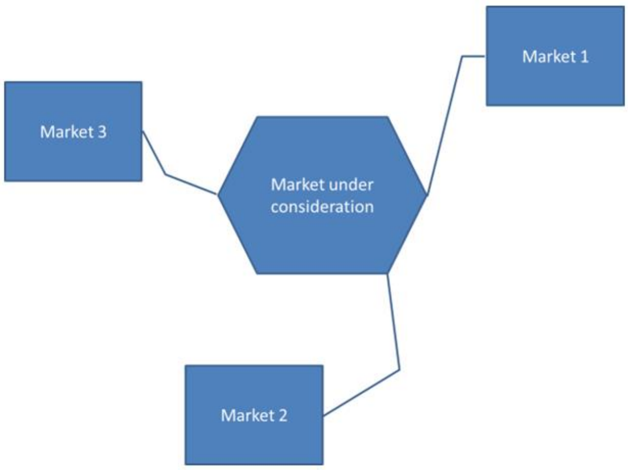

Figure 5: Example Markets

Table 4 - Example of iteration 1 search step

	Iteration 1 Transfer Capacities (MW)						
		Simulation 1		Simulation 2		Simulation 3	
	Baseline	Increment	Simulated capacity	Increment	Simulated capacity	Increment	Simulated capacity
CP Market 1	2000	+1000	3000	0	2000	0	2000
CP Market 2	1000	0	1000	+1000	2000	0	1000
CP Market 3	1000	0	1000	0	1000	+1000	2000
CHANGE IN SEW – CAPEX-ACC	**0**	**+ £7M**		**+ £3M**		**+ £11M**	

The tables below demonstrate the Least Worst Regret step between iteration 1 and iteration 2. Table 5 shows the NPV of a project to each market for the future energy scenario Consumer Power. These figures would be calculated across all four FES to create a table such as below.

Table 5: NPV example of each market across each scenario

Net Present Value (£m)				
	2D	SP	SS	CP
Market 1	12	5	3	7
Market 2	4	1	0.5	3
Market 3	11	2	4	11
Max	**12**	**5**	**4**	**11**

Table 6 Least Worst Regret Example

Regret (£m)					Max regret (£m)
	2D	SP	SS	CP	
Market 1	0	0	1	4	4
Market 2	8	4	3.5	8	8
Market 3	1	3	0	0	3

The regret is then calculated by identifying the difference between the market with the highest NPV in that scenario and the market under review. This is to identify which market should be taken forward. In the example it would be market 3 as shown in Table 7.

Table 7 Example of iteration 2 search step

	Iteration 2 Transfer Capacities (MW)						
		Simulation 1		Simulation 2		Simulation 3	
	Baseline	Increment	Simulated capacity	Increment	Simulated capacity	Increment	Simulated capacity
CP Market 1	2000	+1000	3000	0	2000	0	2000
CP Market 2	1000	0	1000	+1000	2000	0	1000
CP Market 3	2000	0	2000	0	2000	+1000	3000
CHANGE IN SEW – CAPEX-ACC	**0**	**+ £6M**		**+ £2M**		**+ £5M**	

Increased by 1000MW following the result of iteration 1

The search finishes when it is deemed to have converged- that is, no further capacity alterations yield a higher overall present value for the whole study window. The optimal capacity profiles will then be presented in the NOA report, providing the industry with a single recommendation.

To improve efficiency of arriving at the end of the optimal path, the incremental steps will be of 1000MW of capacity. Reviewing the results from NOA IC 2016, it proves that the efficiency of the analysis would be much greater. Once there is no additional benefit from any interconnectors, the incremental capacity will be reduced to 500MW to analyse whether there is any benefit of a further 500MW.

10. Further Output

Accompanying the output of the optimal path market and network analysis, additional results will be provided illustrating the benefit each interconnector would potentially provide. This is to overcome this possibility of misinterpretation of the results, as many interconnectors which don't appear in the optimal path individually have a positive net benefit to consumers and therefore development should continue to be pursued.

11. Process Output

The above methodology will be employed to create a chapter of the NOA 2017 report. This chapter will present the main findings of the analysis - an optimised interconnection capacity level by market, and the best timing for capacity increases across all scenarios. It will include commentary on these results and other impacts of interconnection excluded from the optimisation. This will be delivered by 31st January 2018.

Appendix A: Spackman Analysis

The Spackman approach is the standard approach used by National Grid for determining the Present Value (PV) of project Capital Expenditure (CAPEX) costs.

A helpful summary of the approach is outlined in the following publically available document:

http://www.ofwat.gov.uk/aboutofwat/stakeholders/jrg/pap_tec201207jrgdiscount.pdf

It has been accepted by Ofgem for use on a range of capital investment projects undertaken by National Grid. Its focus is on how discounting should be applied in the case where private finance drives an investment but the benefits accrue to consumers.

In the Spackman methodology the financing or CAPEX costs are converted into annual payments (in other words mortgaged over the economic life of the project) using a fixed annuity factor determined by the firm's projected WACC. The resulting fixed flow of annual costs is then discounted in the usual way using the standard discount rate (in this case the Treasury Green Book Social Time Preference Rate (STPR) of 3.5%).

The benefits are also discounted in the normal way using STPR; there is no change here.

To illustrate the methodology, below is an example where the CAPEX is £100m and is incurred in full in 2022/23.

1) We divide £100m by the annuity factor to determine the annual payments (annuity) over the projects life.

The annuity factor here is: $\sum_1^i (1+WACC)^{-i}$; where i= 25 years

So for a WACC of 6.8% this is £8.43m per year for 25 years.

2) For each year we determine the PV of the annuity payment in the usual way by multiplying the payment amount by the discount rate.

The discount rate is: $(1+STPR)^{-i}$; where i= year of spend.

As each year goes by the PV of the annuity decreases as you would expect.

3) Finally we sum the PV of the annuities per year to give a PV of the total cost. This equates to £121.03M in this case.