3

Network Options Assessment for Interconnectors

Overview

3.1 This chapter provides an overview of the aims of the NOA with respect to interconnectors and details the methodology which the ESO will adopt for the analysis and publication within the fifth NOA report (to be published by 31st January 2020).

3.2 We have continued to develop the NOA for Interconnector methodology. This chapter represents our latest thoughts. We received valuable feedback on the draft methodology which has resulted in further improvements to the methodology. We will continue to develop the NOA for Interconnector methodology by actively consulting, listening and responding to feedback from our customers and stakeholders. This will enable us to revise and improve the methodology, resulting in a NOA for Interconnectors analysis that continues to be of increasing value for our stakeholders.

3.3 For reference, below is a summary of the key features and developments of the previous NOA for Interconnector methodologies.

NOAIC 1 (2015/16)	NOAIC 2 (2016/17)	NOAIC 3 (2017/18)	NOAIC 4 (2018/19)
- Modelled through ELSI - GB consumer surplus only - Price data procured from industry - Only considered existing interconnectors and those applied through C&F - Copper plate model with no transmission constraints	- Modelled through Pan European Market Model (BID3) - SEW as sum of producer and consumer surplus as well as interconnector revenue - Consideration of benefit of additional capacity - Copper plate model with no transmission constraints	*(As per NOAIC 2 plus…)* - Use of FES 2017 backgrounds - Used optimised network found through NOA3 as baseline - Combination of interconnectors and potential reinforcement - Single optimal path generated through a least worst regret approach	(As per NOAIC 3 plus…) - Use of FES 2018 backgrounds, including European FES - Provide a range of solutions by not undertaking least worst regret - Analysis of the impact of interconnectors on system operability

Structure of this section

3.4 This section consists of the thirteen sub-sections listed below:

- **Key changes to 2019/20 methodology -** A summary of the major changes made to the NOA for Interconnector methodology for 2019/20.
- **Key similarities to the 2018/19 methodology -** A summary of which areas of the methodology have remained the same from 2018/19 to 2019/20.
- **Factors for the assessment of future interconnection -** A justification of the factors to be considered in determining whether additional capacity would be beneficial.
- **Cost estimation for interconnection capacity** – The costs associated with an interconnector and how these will be calculated.
- **Cost estimation for network reinforcement** – The costs associated with network reinforcements and how these will be calculated.
- **Components of welfare benefits of interconnection** – This sub-section outlines the concept of Socio-Economic Welfare in relation to interconnection and 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 ESO's current market modelling capabilities
- **Options included within the assessment** – A listing of the options that will be assessed within the modelling.
- **Interconnection assessment methodology** – A description of the method by which the ESO proposes to meet the aims of the NOA in relation to optimal interconnection capacity.
- **Further Output** – Additional results that may be of benefit to stakeholders.
- **Process Output** – How the NOA IC output will be delivered.

Key changes for 2019/20 methodology

3.5 This year we will continue to improve the NOA for Interconnectors analysis by acting on feedback from our stakeholders.

3.6 We will refocus on providing additional value from the main iterative analysis on social economic welfare, capital costs and constraint costs, by drawing greater insights from the use of the European FES, which improve the quality and range of interconnector modelling that drives the NOA IC analysis, as well as improving the GB-specific constraint and network analysis.

3.7 We will revise the method used for setting the interconnector baseline level to ensure that the baseline level of interconnection represents a solution that cannot inadvertently be seen to be favouring specific projects.

3.8 We will use the NOA IC as a signpost to other system operability work being undertaken within the System Operability Framework, rather than attempt to undertake an analysis of the impact of interconnectors on system operability within the NOA IC analysis.

Key similarities to 2018/19 methodology

3.9 We will continue to take into consideration the locational impacts on the GB transmission network in addition to the welfare and capital cost implications, and provide greater insight to ourstakeholders of the effects of interconnection on the network.

3.10 We will continue to focus on Social Economic Welfare, capital costs and reinforcement costs.

3.11 We will use the output from the 2019/20 NOA as the baseline network reinforcement assumptions for the NOA IC analysis: this provides greater consistency between the NOA and NOA IC analysis which we believe is of added value to our stakeholders.

3.12 We intend to use essentially the same iterative method used last year. The studies will involve a step-by-step process, where the market is modelled with a base level of interconnection, including current interconnection levels and projects with regulatory certainty. Four separate solutions will be created and hence a range for the optimal level of interconnection, as in NOA IC 2018/19, which stakeholders felt was more realistic and useful.

3.13 We will continue to calculate Social Economic Welfare for all EU countries as well as for GB and the connecting country. We will investigate whether there is any benefit in calculating the optimal path based on the Social Economic Welfare of GB and the connecting country only.

3.14 We will continue to highlight the impact of interconnection on carbon costs and renewable energy curtailment. Greater focus and value.

3.15 We will provide a similar level of detail to that provided in NOA IC 2018/19, but continue to provide greater insight and explanation into what is driving the results and also improve graphical representation of results. Transparency

3.16 We will continue to develop NOA IC based on stakeholder recommendations.

Factors for the assessment of future interconnection

3.17 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.

3.18 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.

3.19 Two further 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 impact to meeting GB's 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.

3.20 **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.

3.21 **RES integration:** modelling facilities 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.

3.22 Last year, due to the inclusion of the ancillary services analysis, we provided less analysis of carbon costs and RES integration. This year, our stakeholders have stated that they would prefer a renewed focus on environmental factors, with an expanded output on the impact of increased interconnection on carbon costs and RES curtailment, as the debate on what path GB will pursue to transition to a low carbon future continues to increase.

Factors outside the methodology scope

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

3.24 **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. 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.

3.25 **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.

3.26 **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.

3.27 **Ancillary Service costs:** We will not attempt to model the potential impact of interconnectors on services which support system operability. Initial feedback on the system operability analysis undertaken for NOA IC 2018/19 was mixed. The results were complex and difficult to draw high level conclusions from. Some stakeholders felt the analysis placed an inappropriate focus on the benefit or disbenefit of interconnectors on system operability, and that a wider lens would be more appropriate. There were also concerns with the robustness of analysis so far into the future.

3.28 A more detailed analysis of system operability as part of NOA for Interconnectors does not fit well with the high-level market signal approach of other NOA for Interconnectors market analysis work. In addition, the time available for the NOA for interconnectors modelling, which can only commence after the NOA reinforcement recommendations are available and must be complete before the end of January, makes this infeasible.

3.29 We believe a more appropriate solution is to undertake this type of analysis as part of the System Operability Framework which takes a holistic view of the changing energy landscape to assess the future operation of Britain's electricity networks. Interconnectors may be one of a range of potential service providers or may be one of a range of assets that may result in system operability issues. The NOA for Interconnectors analysis can be used as a means of highlighting this work.

Cost estimation for interconnection capacity

3.30 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. 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[15] provides sufficient granularity to differentiate between standard costs of connection to different markets. There are three elements to the capital costs; subsea cable, onshore connection costs and wider reinforcement costs. We will continue to review and investigate alternative robust sources for generic interconnector cost estimates.

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

3.31 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 ENTESO-E Transmission System Map. 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 following table.

Table 3. 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

3.32 Onshore connection costs will be excluded as the interconnector study cases are zone specific but not substation specific.

3.33 Wider reinforcement costs will be included in capital costs for options where applicable.

3.34 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 (these costs include the cost of installation):

Table 3. 2 Standard costs

Total cost per route length (km)	Rating	Mean (€, 2014)
DC cables[16]	250-500kV	757,621
OHL[17]	380-400kV (2 circuits)	1,060,919

[16] 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.

[17] 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.

Underground cables[21]	380-400kV (2 circuits)	4,905,681

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

3.35 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 ESO (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 publicly available Grant Thornton report.[18]

Cost estimation for network reinforcements

3.36 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 3. 1.

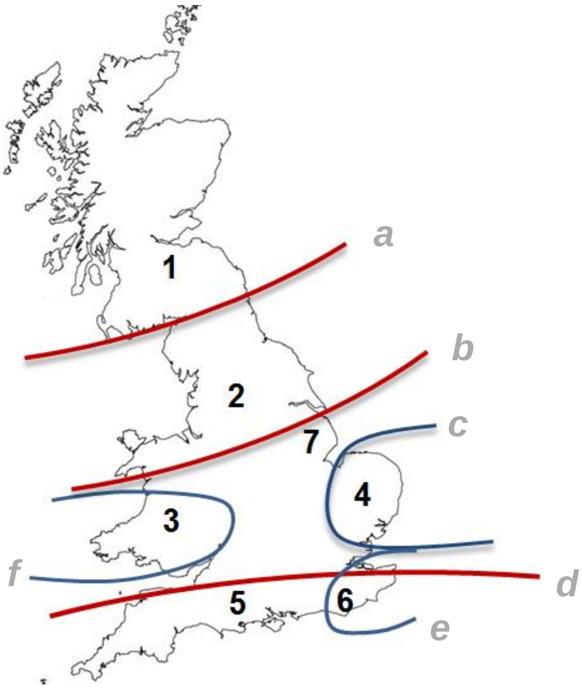

Figure 3. 1 Illustration of Network Zones

3.37 The baseline boundary capabilities will be determined by using the outputs from the main NOA 2019/20 analysis. Additional boundaries, and hence zones may be added if their addition may increase the value of the analysis.

3.38 Generic reinforcements will be created for each boundary. These will be based on where there are high levels of congestion on the network and provide an indication of the level of reinforcements required.

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

Components of welfare benefits of Interconnectors

Introduction

3.39 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.

Social and Economic Welfare

3.40 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 the connected market's SEW values, and the components which make up each.

3.41 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 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.

3.42 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 main NOA IC assessment, as discussed in the previous section.

Effects on Interconnected markets

3.43 Power flow between two connected markets is driven by price differentials. Figure 3. 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.

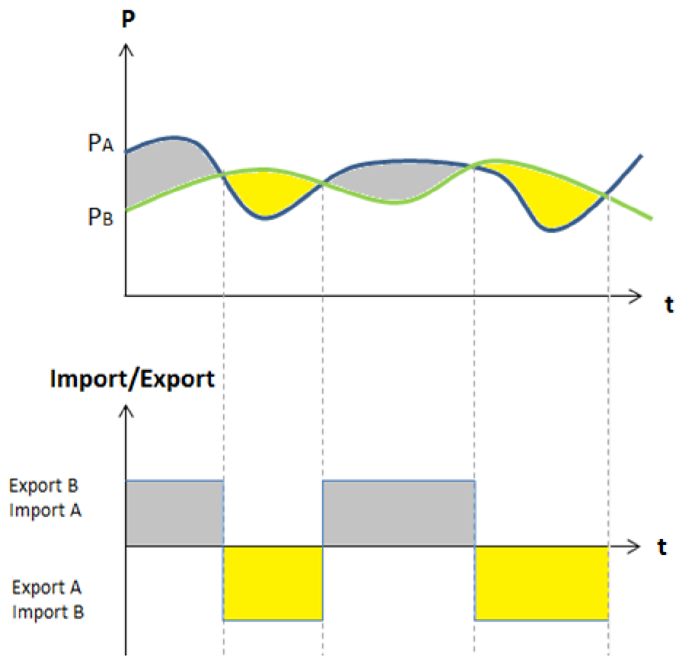

Figure 3. 2 Price difference as import and export driver

3.44 Figure 3. 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.

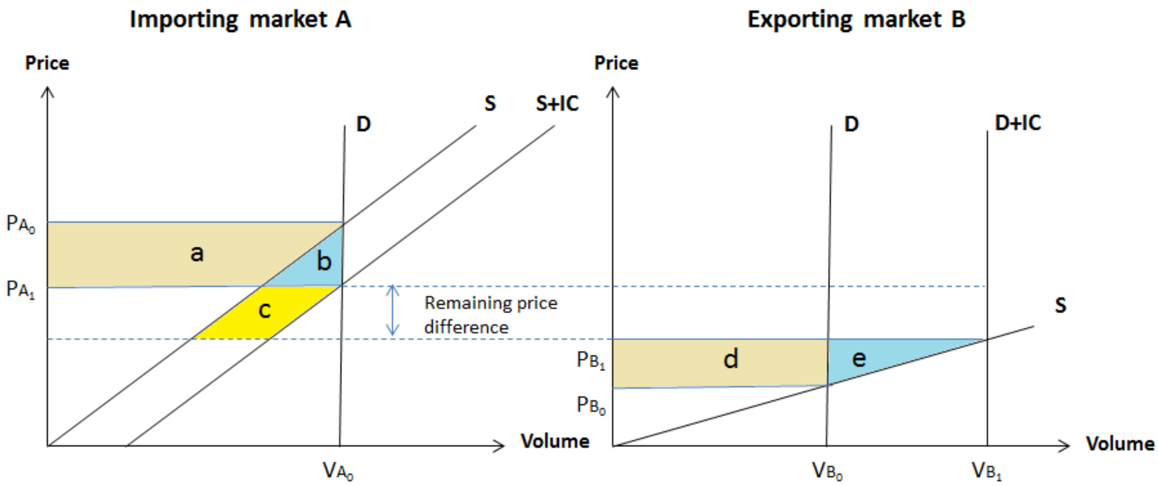

Figure 3. 3 Consumer and Producer Surplus of connected markets

3.45 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 3. 3 shrinks.

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

3.47 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.

3.48 Where the market is modelled with and without some additional interconnection capacity added, SEW 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%.

Constraint cost implications of interconnection

3.49 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. Further detail regarding optimal locations to connect will be output based upon the constraint costs calculated on the network with the interconnectors under consideration.

3.50 Constraint costs are incurred on the network when power that is economically "in merit" is limited from outputting due to network restrictions. In this event, the ESO 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.

3.51 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.

BID3 model

3.52 BID3 is the tool which will be used to perform the NOA IC 2019/20 and employed by the ESO to carry out a range of economic analysis.

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

3.54 A comprehensive guide to how National Grid uses BID3 for calculating constraints is available on our website[19]. It is an economic dispatch model which can simulate all ENTESO-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.

3.55 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.

3.56 The socio-economic welfare is calculated by summing the producer surplus, consumer surplus and interconnector revenue. The consumer surplus is the difference between the

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[19] https://www.nationalgrid.com/sites/default/files/documents/Long-term%20Market%20and%20Network%20Constraint%20Modelling.pdf

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.

3.57 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.

Options included in the assessment

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

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

Table 3. 3 Options to be considered in the analysis

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		

Interconnection Assessment Methodology

Optimisation of GB-Europe Interconnection Process

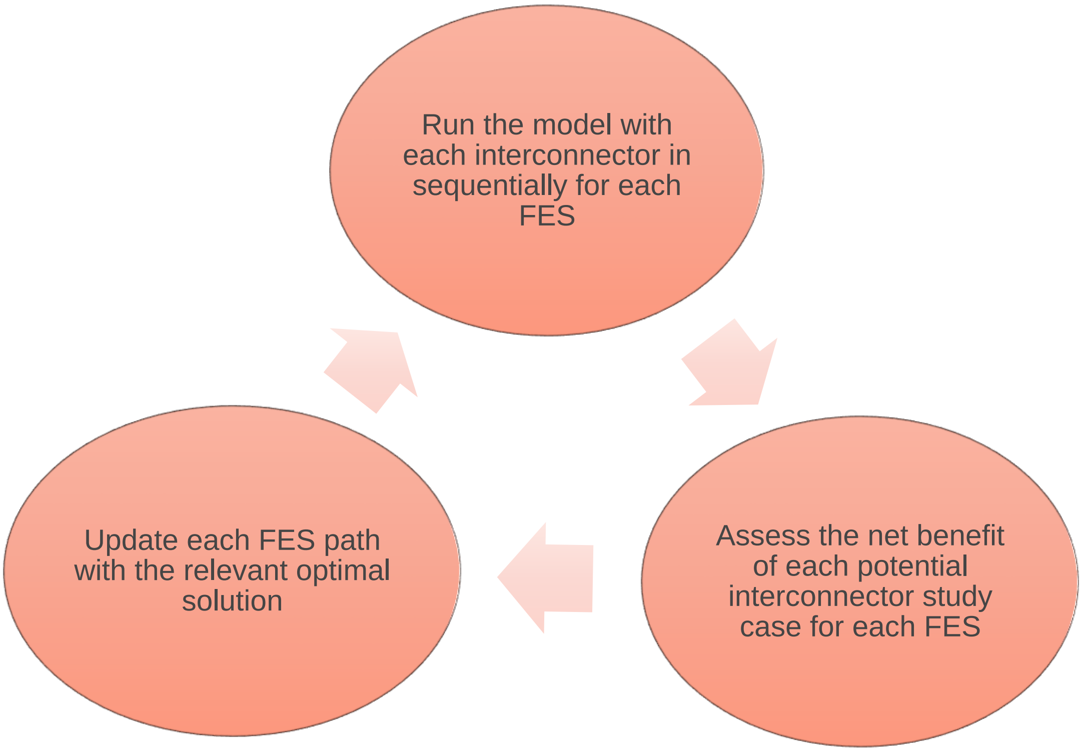

Figure 3. 4 Process summary

3.60 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. 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.

3.61 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.

3.62 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). These levels are defined by the FES European scenarios.

3.63 The market studies, which model the physical limitations of transmission between markets (but not within markets) start from the baseline level interconnection. The interconnection capacities are then adjusted sequentially to search for improvements on this initial point, represented by an increase in the total SEW - CAPEX - ACC following the alteration of the capacity values. This total 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.

Modelling inputs

3.64 The starting point of the process is National Grid's FES 2019 which includes generation plant ranking orders and demand forecasts across Europe for each scenario. FES 2019 will be the second time European markets are being varied by GB scenario to achieve more coherent, higher quality modelling. Output from NOA 2019/20 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 2027 (the first year of study).

3.65 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 IC aims to find what would be economically optimal rather than being based on specific projects. A shortfall of interconnection baseline capacity relative to FES level of interconnection will then drive further interconnection in the results.

3.66 We have received feedback from several parties that we should revisit the approach of setting the baseline level of interconnection. It is important to state that NOA IC does not assess the viability of specific future projects: it does not “pick winners or losers” of actual projects. In NOA IC 2018/19 the interconnection baseline was based on all current interconnector projects and those with a high degree of regulatory certainty. We intend to set a baseline level of interconnection that avoids any unintended perceived project discrimination, and also allows a successful modelling output within defined modelling timescales. One option is to include within the baseline all projects currently under development, or all those with Project of Common Interest status, or all those on the National Grid ESO Interconnector Rregister. This on its own would result in too high a baseline intertconnection level, hence an “uncertainty factor” could be added equally to all of the projects included under development to produce a credible level of baseline interconnection. We will investigate this approach before commencing the NOA for Interconnectors 2019/20 and will provide additional information to our stakeholders.

3.67 The time period considered in the studies extends from the present to 2038. This is to match the FES, which will forecast up to 2039 in detail. For the timing analysis, only capacity in years 2027, 2029 and 2032 will be investigated. The reason for not starting to analyse additional capacity until 2027 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 market simulations as constrained by time limitations.

Market modelling

3.68 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. This year, like last year, based on strong stakeholder feedback, there will be no Least Worst Regret calculation at the end of each iterative step, resulting in four optimal paths: one per FES and hence a range for the optimal solution will be produced. 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 each step.

3.69 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 2026, 2028 and 2031. This means for each iteration, the welfare of the interconnectors in every spot year will be calculated.

3.70 The example below is based on a hypothetical situation, optimising the capacities and optimal timing of connection for potential interconnection to 4 markets. It shows a sample of the options of market, connecting year, FES scenarios, GB zone and reinforcement that need to be considered for each iterative step.

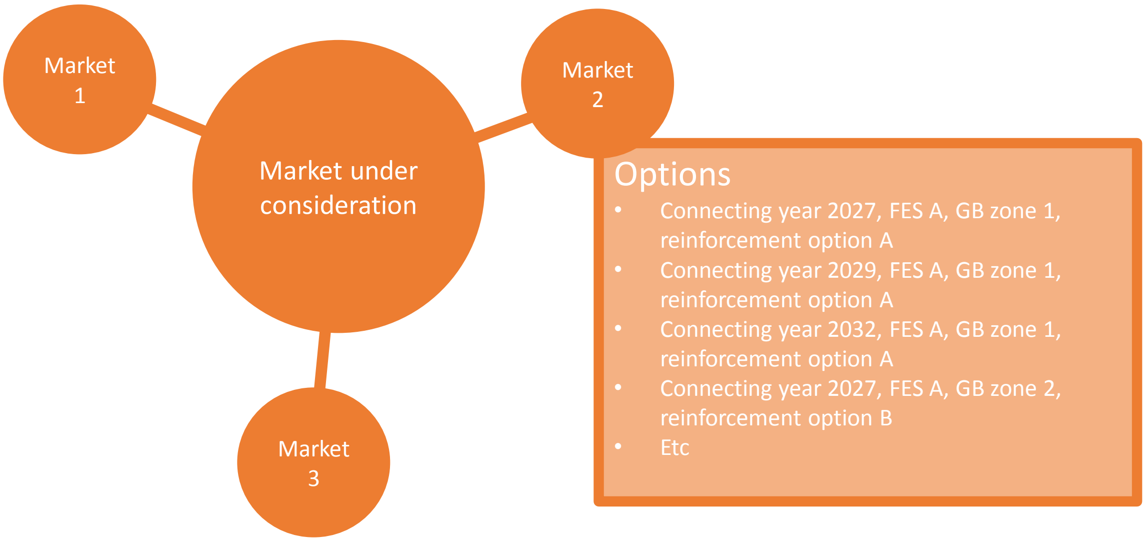

Figure 3. 5 Example Markets

Table 3. 4 Example of iteration 1 search step

	Iteration 1 Transfer Capacities (MW)						
	Baseline	Study case 1		Study case 2		Study case 3	
		Increment	Simulated capacity	Increment	Simulated capacity	Increment	Simulated capacity
FES A Market 1	2000	+1000	3000	0	2000	0	2000
FES A Market 2	1000	0	1000	+1000	2000	0	1000
FES A Market 3	1000	0	1000	0	1000	+1000	2000
FES A **CHANGE IN SEW-CAPEX-ACC**	**0**	**+ £12M**		**+ £5M**		**+ £8M**	

3.71 Table 3. 4 gives an example of the iteration search step 1, whereby an additional 1000 MW of capacity is added sequentially to each option. The option that produces the highest change in SEW-CAPEX-ACC for each FES (in this example study case 1, with an additional 1000MW interconnector to market 1) is then added to the baseline for the iteration search step 2 for that particular FES, as shown in Table 3. 5.

Table 3. 5 Example of iteration 2 search step

	Iteration 2 Transfer Capacities (MW)						
	Baseline	Simulation 1		Simulation 2		Simulation 3	
		Increment	Simulated capacity	Increment	Simulated capacity	Increment	Simulated capacity
FES A Market 1	3000	+1000	4000	0	3000	0	3000
FES A Market 2	1000	0	1000	+1000	2000	0	1000
FES A Market 3	1000	0	1000	0	1000	+1000	2000
CHANGE IN SEW – CAPEX-ACC	**0**	**+ £7m**		**+ £5M**		**+ £5M**	

FES A Market 1 Increased by 1000MW following the result of iteration 1 for FES A

3.72 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 for each scenario. The optimal capacity profiles will then be presented in the NOA report, providing the industry with a range, that is one for each FES.

3.73 To improve efficiency of arriving at the end of the optimal path, the incremental steps will be of 1000MW of capacity. 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.

Further Output

3.74 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.

Process Output

3.75 The above methodology will be employed to create a chapter of the NOA 2019/20 report. This chapter will present the main findings of the analysis – a range for 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. The analysis aims to provide stakeholders with a quantified assessment of the potential benefits of interconnection. The output from the 2019/20 NOA is used as in input into the NOA IC analysis for setting the baseline network reinforcement assumptions. The output of NOA IC does not feed directly into the creation of the next set of FES. The FES level of interconnection is calculated on a project by project basis, whereas NOA IC aims to find what would be economically optimal rather than being based on specific projects. Our stakeholders have restated that they want us to keep the level of detail similar to that within NOA IC 2018/19, but with greater insight. The results will be delivered by 31st January 2020.