Ofgem

FUTURE INTERCONNECTORS ASSESSMENT FRAMEWORK

Needs case assessment framework

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Executive Summary

Ofgem appointed Arup to develop a new needs case assessment framework for interconnectors and multi-purpose interconnectors (MPIs) to enable an effective and transparent decision at the initial project assessment (IPA) stage of the cap and floor (C&F) regime from Window 3 onwards. This included identifying the underlying indicators and associated methodologies required for the assessment.

Historically, significant price differentials and limited interconnection capacity to Great Britain (GB) translated into a strong positive correlation between incentives for developers and benefits for GB consumers, as new interconnections would increase the import of cheaper electricity. However, as interconnection capacity increases and more renewable generation is deployed both domestically and in Europe, structural price differentials are likely to decrease in the long-term, whilst short-term price volatility would increase. This in turn could weaken the traditional correlation between additional interconnection and increased consumer welfare. Nonetheless, interconnectors can deliver other significant wider benefits such as flexibility, system operability, security of supply and potentially decarbonisation, which are not currently fully captured.

Arup has reviewed Ofgem's needs case assessment framework, as well as alternatives from other sources, and provided options for improvements. Based on the analysis conducted, the main conclusions can be summarised as follows:

- **Overall, Ofgem's needs case assessment framework is broadly fit for purpose because its theoretical scope is comprehensive. The current framework already captures some of the wider impact categories identified during the interconnector policy review. However, it also presents some shortcomings**.
  - Ofgem's decision-making relies almost exclusively on socio-economic welfare (SEW) impacts. Overall, the modelling underpinning the SEW analysis can be considered fit for purpose and it should therefore be replicated in future assessments. Arup suggests implementing relatively minor changes described in Chapter 2.
  - Impacts on decarbonisation and security of supply were assessed only qualitatively, whilst flexibility impacts were not considered at all. More importantly, it was not clear how these impacts were considered when reaching a final decision at the IPA stage. As the economics of interconnector projects change, it will be vital for Ofgem and project developers to assess and showcase the entire spectrum of potential interconnector impacts.
- **Of the alternative assessment frameworks reviewed by Arup, the European Network of Transmission System Operators for Electricity's (ENTSO-E) Cost Benefit Analysis (CBA) guidelines appear to be the best reference points to improve Ofgem's assessment framework**.
  - These specifically assess interconnector impacts from either a technical or economic perspective, providing a broad range of standard indicators and relevant methodologies for the quantification, and where possible, the monetisation of the wider impact categories Ofgem has decided to include in its framework, and that are not currently fully captured.
  - Arup has also identified overlaps and synergies between the analysis that Ofgem and National Grid Electricity System Operator (NGESO) conduct in relation to interconnectors. In the longer term, as the role and responsibilities of a Future System Operator (FSO) are defined, Ofgem may consider making the FSO the single party responsible to run the calculations of the SEW analysis. Ofgem would maintain its role of final and only decision maker.
- **Based on its review and dedicated workshops with key stakeholders, Arup recommends Ofgem to adopt a new list of indicators.** This list, described in Chapter 3, includes a selection of quantitative and qualitative indicators describing seven standalone impact categories: SEW, network costs, decarbonisation, system operability, flexibility, security of supply and hard to monetise impacts.

    - Most of the new indicators can be extrapolated from the SEW analysis. Arup recommends Ofgem to procure a specialist consultant to run such analysis, as has been done in the past.
    - Compared to previous application windows, Arup suggests making the submission of the SEW analysis from the developers optional, rather than mandatory. If developers wish to, they should be allowed to submit their own analysis as complementary information to Ofgem as part of their application. This will inform the modelling workshop shaping Ofgem's own SEW analysis. Ofgem should review this information and clearly describe how it has been considered, and why.
    - The information developers will be required to submit to Ofgem will be limited to project costs, network costs, alignment with Grid Code ECC.6.3.19 GRID FORMING CAPABILITY if applicable, information on expected hard to monetise impacts, and other relevant technical project information.
    - NGESO remains the best placed party to assess impacts on system operability and flexibility, as it holds the necessary data and the required modelling and analytical expertise for doing so.
- **Arup recommends Ofgem use the same list of indicators for the assessment of MPIs.**
    - Arup did not identify any idiosyncratic impacts linked to MPI projects that are not already captured by the proposed list of indicators. Additionally, using the same assessment framework will ensure a certain degree of consistency in how interconnector and MPI projects are assessed.
    - For the calculation of an MPI's SEW impacts, whilst consistency in the assessment should be maintained, some aspects of the modelling required will differ from that of an interconnector. These will be dictated by how Ofgem and project developers intend to define key design, regulatory and commercial aspects underpinning the project, which in turn will determine how it will behave in a market simulation. Arup provided its suggestions in Chapter 3.
- **Arup recommends that Ofgem adopts a multicriteria assessment framework that brings together both quantitative and qualitative indicators to support its decision-making process at the IPA stage.**
    - The framework described in Chapter 4 allows Ofgem to assess a broader range of impacts through a much more granular and detailed level of information compared to the past, and to consider the trade-offs each project presents.
    - The framework also presents features that can be used to prioritise or shortlist projects based on the impact categories that Ofgem thinks better represent consumers' interests, rather than through pre-determined weighted scores. In this way, the framework will support Ofgem in reaching a final decision in a clear and transparent way, rather than determining it automatically on its behalf.

1. Introduction

Chapter summary:

Following its review of the interconnector regulatory framework, Ofgem has appointed Arup to review the framework it uses to assess stakeholder impacts when applying for regulatory approval.

1.1. Context

In August 2020, Ofgem launched a review of the C&F regime, the regulatory policy framework in place to develop new electricity interconnectors to GB. Following its development for Nemo Link as a pilot project from 2011, the regime was first introduced in 2014 to incentivise the development of interconnectors by providing long-term revenue security for investors, whilst ensuring benefit to GB consumers. Since then, two application windows have been held in 2014 (Window 1) and 2016 (Window 2), awarding a C&F regime to nine interconnector projects with a total capacity of 10.9 GW, bringing the total GB interconnector capacity to 15.9 GW once completed.

Considering the significant increment of interconnector capacity and the substantial changes in the UK's energy landscape over the last decade, in August 2020 Ofgem decided to review the regulatory policy and approach ahead of any further C&F application windows.[1] This was to ensure that further interconnections and the regulatory framework for their delivery remain in consumers' best interest.

The review focused on four key workstreams, treated in four distinct consultation papers published during 2021, described below:

- Workstream 1: Review the C&F regime to date and evaluate whether the objectives have been met. Ofgem also planned to identify any areas of improvement to the regulatory design of the C&F regime and the structure of the assessment framework.
- Workstream 2: Socio-economic modelling to determine whether future interconnection remains in the interest of the consumers.
- Workstream 3: Determine whether the current method of project assessment requires a change to reflect the full range of potential impacts, including flexibility, system operability costs, decarbonisation, and security of supply.
- Workstream 4: Review of the final conclusions of the Integrated Transmission Planning and Regulation (ITPR) and consideration of regulatory options for Multiple Purpose Interconnector (MPI) projects.

In December 2021, Ofgem published its decision on the interconnector policy review,[2] setting out the next steps for GB interconnector regulation for the future and confirming the opening of a third C&F application window (Window 3) for interconnectors and a C&F pilot scheme for MPIs in mid-2022.

A key outcome of the decision was to review the Ofgem's needs case assessment framework used to determine whether projects applying for a C&F regime were in the interest of consumers. This was in recognition of the far-reaching impacts interconnectors can have on the energy system which can be broadly captured under the four categories – decarbonisation, system operation, flexibility and security of supply.

Whilst the assessment framework used so far by Ofgem captured aspects of these wider impacts, it was recognised that this was not conducted in full and that there was scope to improve how these wider benefits were assessed. The economics behind interconnector projects is rapidly changing in the current net-zero context. As interconnection capacity increases and more renewable energy sources (RES) generation

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[1] Open letter: Notification to interested stakeholders of our interconnector policy review (ofgem.gov.uk)

[2] Interconnector Policy Review: Decision (ofgem.gov.uk)

capacity is deployed to meet the UK climate targets, the structural price differentials between GB and its neighbours' electricity markets are reduced, affecting the distribution of SEW between consumers, producers and interconnector developers. However, interconnectors can play a key role in managing intermittent renewable energy generation, meeting peak electricity demand by providing flexibility to the energy system, as excess generation can be shared with connecting countries. This could also potentially reduce constraint costs as well as increase security of supply. This highlights the renewed importance of a correct and complete assessment of these benefits to ensure the nature and measure of potential impacts of new interconnectors are accounted for.

1.2. Scope and structure of this report

Within this context, Ofgem appointed Arup to develop a new needs case assessment framework for interconnectors and MPIs to enable an effective and transparent decision at the IPA stage of the C&F regime, including the underlying indicators and associated methodologies. The framework needs to combine both qualitative and quantitative indicators in order to capture as many impacts as possible, including those on decarbonisation, system operability, flexibility, and security of supply.

This report provides a list of suggested indicators and an overarching multi-criteria assessment framework to support Ofgem's decision-making process at the IPA stage, indicating the appropriate methodologies and the best-placed parties to conduct the analysis.

The remainder of this report is structured as follows:

- Chapter 2 presents a critical review of Ofgem's current assessment framework and the key stakeholders' feedback collected during Ofgem's interconnector policy review. It also includes an overview of other relevant assessment frameworks and the initial findings of our analysis.
- Chapter 3 presents the list of indicators and underlying methodology to be used in the assessment of interconnector and MPI projects. Key methodological considerations and best-placed parties to implement each methodology are also highlighted.
- Chapter 4 describes the multi-criteria assessment framework combining the evaluation of monetizable, quantifiable and non-quantifiable indicators to enable a robust and transparent decision-making process at the IPA stage.

There are also several appendixes included in this report:

- Appendix A provides an overview of the modelling approach used in the past by Ofgem's consultant when assessing new interconnector projects.
- Appendix B contains an overview of methodology used to determine economic impacts of interconnectors delivering Ancillary Services for Window 2.
- Appendix C lists hard-to-monetise impacts considered in the previous assessment framework by Ofgem.
- Appendix D lists all the benefits indicators considered in the ENTSO-E CBA guidelines.
- Appendix E describes the ENTSO-E and BEIS approaches to determine the interconnector's impacts on system flexibility.
- Appendix F summarises key modelling assumptions to be considered in the needs case assessment.
- Appendix G compares the information required from developers at Window 2 against future windows under the new assessment framework.

2. Review of needs case assessment frameworks

Chapter summary:

In this chapter, Arup firstly reviews Ofgem's assessment framework and the feedback provided through the interconnector policy review. Arup has found that the theoretical scope of the framework is fit for purpose, but currently it does not allow for the quantification of the wider impact categories identified by Ofgem. Arup has also found the analysis of SEW impacts, the core element of the framework, is fit for purpose, and suggested relatively minor changes or its improvement.

In order to identify the key gaps of Ofgem's assessment, Arup has reviewed other relevant frameworks that could be used to improve it, providing its opinion on each of the frameworks considered and how to integrate them into Ofgem's assessment.

2.1. Overview of Ofgem's current approach

Ofgem's needs case assessment of new interconnector projects applying to Window 2 of the C&F regime included both quantitative and qualitative analysis to inform its decision-making process at the IPA stage.[3] Ofgem has historically considered the impact of new interconnectors through four main categories:

- impacts on SEW in GB, determined by projected electricity flows between the connected markets;
- impacts on the operation of GB's electricity transmission system;
- network costs needed to accommodate a new project;
- qualitative assessment of hard-to-monetise impacts, including strategic and sustainability benefits that the projects may provide.

In the following sections, Arup provides a description of each of these impact categories and how they were assessed.

2.1.1. Socio-Economic Welfare (SEW) impacts analysis

The SEW analysis focussed on:

- the value of the interconnector projects (both costs and revenues) to the developers;
- the socio-economic impacts of these projects on GB, the connected country, and the wider European region, including those on wholesale electricity prices, consumer surplus, producer surplus and other interconnector owner profits; and
- the impact of these new interconnector projects on C&F payments from and to consumers under the regime.

The analysis was based on projected electricity flows resulting from each interconnector, calculated through a pan-European power market dispatch model (BID-3) simulating optimal plant dispatch and electricity prices on an hourly basis under three different scenarios (Base Case, High interconnector value and Low interconnector value). These scenarios aimed at assessing a reasonable range of outcomes for the overall economic benefit of new interconnection by examining a range of drivers and assumptions. The time horizon considered covered a period from 2022 and 2040, whilst the model was run for five spot years (2022, 2025,

[3] We note that assessment between Window 1 and Window 2 projects differed, although only slightly. We have therefore based this review on the assessment framework used for Window 2 projects being the most recent.

2030, 2035 and 2040). Results were extrapolated between spot years to produce an overall Net Present Value (NPV) calculation for each interconnector over the period studied.

To assess the impacts of each interconnector and the interaction among multiple projects, the analysis was conducted using two approaches:

- First additional (FA) approach: this examines the value of each proposed interconnector as if it were the only new interconnector built as scheduled.
- Marginal additional (MA) approach: this examines a project that is commissioned at the same time as the other projects assessed, and no other projects are built after that.

Focus - Evolution of the SEW modelling

Ofgem commissioned a consultancy [4] to conduct a social welfare CBA to support Ofgem decision-making at the IPA stage at Window 2 (hereafter the 2017 report). [5] This analysis focussed on determining how the specific new projects proposed at Window 2 would impact the SEW of consumers, producers and interconnector owners in GB and a connected country.

The same consultancy was procured in 2020 to inform Ofgem's consultation paper for Workstream 2 of the interconnector policy review (hereafter the 2020 report).[6] This report advised whether further interconnection capacity beyond the projects approved so far under the C&F regime was likely in the interests of GB consumers from a socio-economic perspective.

The nature and details of the analysis in the 2017 report differs from the 2020 report. The former was a more detailed and comprehensive CBA of actual projects, whilst the latter was a high-level assessment of notional projects. The 2020 report required an additional analytical step to identify the notional projects to assess based on the Internal Rate of Return (IRR) (i.e. the selected project representing the commercial attractiveness of the notional project).

Ofgem confirmed this additional step will not be part of the SEW analysis in the future application windows. On the other hand, the underlying modelling approach and methodology used to determine SEW impacts have remained consistent across all the consultant's reports. Arup has considered both in this report and highlighted key differences where necessary.

Main costs and benefits included in the consultants' SEW analysis

The consultants' analysis considered the following costs and benefits, split into three main stakeholder categories:

- Net consumer welfare change:
    - Savings or increases in costs for electricity consumers due to changes in the wholesale electricity prices from the introduction of the new interconnector.
    - Payments to or from consumers as part of the forthcoming C&F regime.
- Net producer welfare change:
    - Changes in the gross margin for energy production. This can be: an increase in gross margin from increased exports and/or higher prices in hours when they generate; or a decrease from increased imports and lower prices.

[4] Pöyry Management Consulting (currently AFRY Management Consulting).

[5] Near-term interconnector cost and benefit analysis – independent report.

[6] Ofgem interconnector policy review – independent report by AFRY

- Net interconnector welfare change:
  - Direct revenues from arbitrage payments, which can be captured by the interconnector owner. It is important to note that it was assumed that interconnectors receive all arbitrage payments directly as they would in an implicitly coupled market structure.[7]
  - Costs associated with the construction and operation of the interconnector, including electricity transmission losses. These were based on developer submissions to Ofgem.
  - Payments made or received under the C&F regime.
  - Indirect revenue impacts on other interconnector owners (i.e. 'cannibalisation' effect) where a flow on one interconnector may lead to greater or lesser revenue on another interconnector.

In the 2017 report, three other benefit categories were considered given the potentially significant impacts they could have on the results, listed in the Table 1 below. These impacts were not reported individually but were considered in the calculations of the final SEW impacts to better represent reality.

Table 1 - Additional Benefits Included in the SEW Analysis for Window 2 Run by Ofgem's Consultants

Welfare drivers	Description
Changes in low carbon support payments	The effect of interconnectors on prices feeds through to all consumers and producers. However, if low carbon producers can access higher market prices, the burden on consumer support is reduced under low carbon support schemes such as UK Contracts for Difference (CfD) or broader Feed in Tariff (FiT) mechanisms. The opposite can also happen. The impact on CfDs or FiT shifts the welfare value between consumers and producers within one country as well as the split of welfare between countries. However, the overall effect on countries is unchanged.
Capacity Market	Interconnectors can access additional revenues by participating in capacity mechanisms on one or both sides of an interconnector. This revenue would then contribute towards the calculation of the C&F payments and reduce the likelihood of floor payments.
Cannibalisation effect	New projects can significantly change the C&F payments from and to existing interconnector projects under the regime.

More detail on the BID-3 model and the modelling approach followed at Window 2 can be found in Appendix A of this paper.

Cost and benefits not included in the consultants SEW analysis

The consultant also identified several other benefit categories, summarised in Table 2 below. These were subsets of the welfare categories listed above either too difficult challenging to extrapolate, or simply too difficult to model. Therefore, the consultant decided not to include them in the 2017 report.

[7] In reality, interconnector owners can also sell physical transmission rights for future explicit capacity auctions on longer time frames (i.e. beyond day-ahead trading). Ofgem's consultant did not include these revenues in their analysis, possibly to simplify the modelling of interconnector welfare.

Table 2 - Summary of Costs and Benefits not Included in the SEW Analysis for Window 2 Run by Ofgem's Consultants

Group	Welfare driver	Description	Assessed by
Consumers	Changes in network costs	Changes in network reinforcement costs and other network- related costs, such as network driven curtailment caused by a new interconnector.	Information provided by National Grid Electricity Transmission (NGET), as part of the assessment process for Window 2 (the NGET 2017 analysis)
	Improved security of supply	Lower likelihood and therefore expected costs from unserved energy in certain periods. This benefit was considered too complex to quantify as the counterfactual situation (i.e. what would be done instead of building an interconnector) is very hard to define. The consultant suggested that another way to consider this benefit is to determine the avoided investment needed for additional large generation capacity, which could affect capacity market clearing prices.	Not assessed
	Lower cost ancillary services	Interconnectors can benefit consumers by providing cheaper ancillary services and balancing services (translating into lower pass-through of costs from the network operator), although these costs could increase rise either through increased requirements from the network operator or because ancillary services are being supplied elsewhere.	Information provided in the NGET 2017 analysis
	Competition	Interconnectors can bring enhanced competition and liquidity for the connected markets, bringing improvements to consumers via increased operational efficiency of operation of the underlying electricity market.	Not assessed
	Other	Additional environmental benefits from enhancing the ability of a system to integrate renewable generation and provide additional carbon savings (where the value to consumers is over and above that recognised in market prices).	Not assessed
Producers	Reduced generation capacity needs	The ability of interconnectors to enable sharing of generation capacity across market borders can off-set the need for new capacity in one market, although this would likely create the need for new capacity build in one or both markets.	Not assessed
	Changes in revenues	Capture of arbitrage revenues if and where the interconnector capacity is offered for sale in explicit capacity auctions. Changes in payments for ancillary and balancing services either through access to additional markets for those services or through displacement of that provider of ancillary services by other sources through the interconnector. Changes in producer revenues from the capacity mechanism.	Not assessed
Interconnectors	Changes in revenues	Revenues from additional rescheduling of interconnectors in intra-day time frame. Revenues from providing Transmission System Operator (TSO) to TSO, ancillary and balancing services between markets.	Not assessed

2.1.2. Impacts on the operation of GB's electricity transmission system

The assessment was based on ad hoc qualitative and quantitative analysis provided by NGET, which provided an overview of the range of ancillary services which interconnectors can facilitate, and the potential benefits associated with such services for the end consumer.[8]

High Voltage Direct Current (HVDC) links such as interconnectors use either Current Source Converter (CSC), or Voltage Source Converter (VSC) technology. The latter, being a more recent technology, is typically used in most new interconnector project, and it facilitates the delivery of ancillary services such as:

- Frequency Response;
- Reactive Response; and
- Black Start capability.

These services can potentially be provided at a lower cost compared to generation assets (the traditional provider of ancillary services to the Energy System Operator (ESO)) as they are the inherent capabilities of the voltage source HVDC technology.[9]

NGET also assessed constraint costs implications of the interconnectors considered. These costs are instead a function of the energy prices in the interconnected markets and the modelled system marginal price for GB. The difference between these prices determines the direction of the interconnector's flows, which in turn impact the electricity flows within the GB system. To maintain the system operative, the ESO is then required to curtail generation where necessary to relieve instances where power transfer is greater than the actual transmission capacity.

The analysis was run for each of the Window 2 projects on scenarios selected from the FES in order to assess the range of impacts. A power market dispatch model and a network model were used to simulate the interconnector flows and their impacts on the system. These where then monetised to determine potential cost savings. The results were modelled for three spot years. A more detailed overview of the methodology used by NGET can be found in Appendix B.

The analysis run by NGET was based on price sensitive information, the release of which could have compromised the ability of the ESO to obtain these services at the most competitive rates. Therefore, Ofgem published only a redacted version of NGET's analysis removing the monetary value of the interconnectors' impacts and providing an accompanying qualitative narrative in its 2017 IPA consultation paper.[10]

Overall, in Arup's opinion, the modelling methodologies used by NGET seemed broadly reasonable and appropriate for the analysis required. Considering the complexities linked to quantifying and monetising ancillary services, NGET's methodology represents a good proxy for these impacts.

However, considering that all the assessed projects were expected to provide positive impacts under ancillary services and constraints management, it was not clear how determinant the information provided by NGET was in Ofgem's decision at the IPA stage. Additionally, because the underling modelling assumptions used by NGET differed from the Ofgem's consultant (e.g. the scenarios considered), it was not possible to aggregate the monetised benefits that the projects could have delivered with the expected SEW impacts. Similarly, the need to redact the results of the analysis negatively affected the overall level of transparency of Ofgem's decision making process and did not allow for a clear comparison of each project's potential impacts.

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[8] NGET report to Ofgem – qualitative analysis of interconnector benefits

[9] It is worth noting that, with increasing connection of distributed energy resources and innovation projects such as CLASS and NGESO Pathfinder projects, new and novel ancillary service providers are entering the market, thus making it more difficult to assess the contribution of traditional providers.

[10] Cap and floor regime: Initial Project Assessment of the GridLink, NeuConnect and NorthConnect Interconnectors

2.1.3. Network costs

Onshore reinforcement costs reflect the expenditure of wider works that is required to connect each interconnector to the transmission system. The costs are recovered through Transmission Use of System (TNUoS) charges, which are paid by users of the transmission network. These estimates were also contained within each project's Connection and Infrastructure Options Note (CION). An overview of the CION process and the underlying methodology is provided later in this chapter.

These costs were modelled by NGET as part to the CION process and were considered in the quantitative assessment of GB SEW impacts and netted off the GB consumer and total GB SEW figures presented in Ofgem's 2017 IPA consultation paper. However, the disaggregate network costs associated to each project were not published, given the commercially sensitive nature of this information. As for the impacts described in the section above, this negatively affected the overall level of transparency of Ofgem's decision making process and did not allow for a clear comparison of each project's potential impacts.

2.1.4. Assessment of hard-to-monetise impact

This assessment focussed on impacts that interconnectors can have on long-term, wider strategic and sustainability factors listed in Ofgem's impact assessment guidance at the time.[11] The assessment was based on information provided by the project developers alongside internal analysis focusing on various sub-categories.[12] Ofgem provided a high-level narrative describing how interconnectors in general would perform under each of them, as this assessment was not project specific.

Arup also notes that within this assessment, Ofgem also provided a high-level and non-quantified assessment of the impacts each interconnector could have on ancillary services, security of supply and the decarbonisation of energy supplies in GB. This was largely based on information contained in the NGET 2017 analysis and the 2017 report.

2.2. Ofgem proposals under the interconnector policy review and key stakeholders' feedback

As described in Chapter 1 of this document, one of the key proposals put forward by Ofgem was the review of the assessment framework describe in section 2.1.

Stakeholders were asked to provide their feedback on it throughout the interconnector policy review. For the purpose of this document, Arup has summarised below the key feedback provided under Workstream 2 and 3, as these workstreams directly relate to Ofgem's approach to assess SEW impacts and wider interconnector impacts, respectively. For the purposes of this document, Arup considered only the key feedback that can be used to inform how to model or assess the impact categories Ofgem has decided to include in its needs case assessment framework.

As noted in section 2.1.1, the 2020 report slightly differs from those used to support Ofgem's decision at the IPA stage. Therefore, Arup has included only the feedback related to general aspects of the SEW analysis that can be used to improve future assessments (e.g. the modelling approach used). Arup excluded feedback targeting more specific elements of the analysis conducted (e.g. specific values for commodity price assumptions or generation mixes, its final results, etc.), as well as any feedback related to the additional analytical steps used by the consultant in the 2020 report (also described in section 2.1.1), as this will not be part of future assessments at the IPA stage.

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[11] Ofgem Impact Assessment Guidance 2016. In May 2020, Ofgem published an updated version of its guidance.

[12] These are described in more detail in Appendix C

2.2.1. Feedback on SEW impact analysis

Stakeholders' feedback on Ofgem's SEW analysis focused on two main areas: scenarios development and overall modelling approach.

Scenarios

Stakeholders highlighted the risks of inconsistency from using different sources and how those sources were combined to build scenarios, especially for the net zero scenario. An example of this was the need for the consultant to modify interconnector capacities across scenarios to ensure internal consistencies.

This might explain general disagreement with some underlying assumptions such as weather patterns, carbon and commodity prices, and the granularity of the data considered. Similarly, there was disagreement on the assumptions regarding capacity mixes, influencing the projected electricity prices used in the modelling.

Few stakeholders suggested to consider a wider range of alternative scenarios and key sensitivities such as electricity prices, or the progress of decarbonisation policies (e.g. closure programmes of coal generation capacity), that could influence SEW impacts or the distribution of welfare between producers, consumers and interconnectors. Finally, few stakeholders noted the relatively short time period modelled (up to 2040), compared longer time frames indicated in the Green Book. See Arup's view in Table 3.

Modelling approach

In terms of modelling approach, one stakeholder indicated that the BID-3 model used by the consultant was not appropriate for the objectives of Ofgem analysis. This is because BID-3 is a linear deterministic model, generally not suited to analyse individual investments. Rather, it is used to assess large scale system optimisation by making a number of simplified assumptions. It was also indicated that the demand is considered to be inelastic and that generator investments are assumed to be exogenous instead of being endogenous.

Regarding the interconnector baseline, one stakeholder also stated that it was too limited and selected based on the wrong criteria. It also suggested that additional baselines should have been considered to reflect different potential realities, for example to factor that some projects might not be built or delivered late.

Concerning the modelling of interconnector revenues, one stakeholder suggested that the inclusion of stochastic weather patterns would be increasingly important due to the effect on RES deployment. Stakeholders also indicated that ancillary services and capacity market revenues were not considered when modelling potential future interconnections in the 2020 report, although they acknowledged the difficulty to forecast them. Arup notes that the 2017 report did include capacity market revenues.

There were also contrasting views on whether to model revenue on an Intra-Day (ID) basis. Some stakeholders noted that the increasing penetration of highly volatile RES generation would suggest a shift of interconnector value within the electricity wholesale markets towards shorter trading time frames, which the current modelling approach does not consider. On the contrary, one stakeholder argued ID revenue effects were likely to be limited due to the relative size of these markets compared to: Day-Ahead (DA), historical observations of weaker price spreads (in implicit auctions) and lower prices for capacity (in explicit auctions) in ID markets.

Finally, another key modelling assumption contested was that the consultant assumed implicit trading arrangements between the UK and the European Union (EU), potentially overestimating the socioeconomic impacts of the UK no longer being part of EU's internal energy market.

2.2.2. Feedback on the assessment of wider impacts

Generally, stakeholders agreed with Ofgem's proposal to incorporate, in its assessment framework, the wider impacts defined in the consultation paper for Workstream 3 on decarbonisation, flexibility, security of supply and system operation.

Few stakeholders also suggested that Ofgem should consider other areas, such as the level of resilience provided by high-voltage direct current systems, the local environmental impact of building new interconnectors both onshore and offshore, and the impacts of new interconnection on competition in the market.

In terms of decarbonisation, stakeholders stressed the importance of defining a robust methodology to correctly account for changes in carbon emissions and to understand the actual carbon intensity of the electricity traded across an interconnector. This would help determine whether interconnectors support or hinder the green transition in the UK by importing carbon intensive energy and exporting green generation.

Concerning flexibility and system operability impacts, several stakeholders indicated the need to clearly define what would be assessed under these categories to avoid double counting of costs and benefits given the close relation between them. Concerning flexibility impacts more specifically, one stakeholder suggested that interconnectors could contribute not only to intraday flexibility, but also to day-to-day flexibility.

Finally, in terms of security of supply, some stakeholders highlighted that Ofgem currently does not consider the risk of displacement of domestic generation due to imports of cheaper electricity from abroad, which further reduces the security of supply in the UK.

2.2.3. Arup's review of stakeholders' feedback

SEW impact analysis

Arup found that the analysis of Ofgem's consultancy to calculate SEW impacts was robust, transparent, and therefore fit for purpose overall. The analysis conducted was comprehensive, and it captured the fundamental changes in welfare of the key stakeholders' categories (i.e. consumers, producers, and interconnectors). Modelling tools, methodological approach and decisions were also adequate and should be replicated in future needs case assessments.

However, Arup agrees with some of the feedback stakeholders have shared, and it has provided its views on how to address it in Table 3 and Table 4 below.

Table 3 - Arup's View on Relevant Stakeholder Feedback Relating to Scenarios Development

Stakeholder feedback	Arup's view
Scenario inconsistency, lack of transparency in determining a net zero scenario.	Stakeholders indicated that a preferable approach would have been to use the national equivalent of the annual FES scenarios for the key countries modelled. In Arup's opinion, this is a reasonable approach. This would ensure using the most up to date scenarios and datasets for each country (which therefore would be aligned with the latest energy and climate policy targets), if available. Arup suggests taking the FES scenarios and pair them up with the FES national equivalent or Ten-Year Network Development Plan (TYNDP) scenarios based on the set convergence criteria such as -but not limited to – the speed of decarbonisation, whether net zero is achieved or not, the level of decentralisation and other demand and supply drivers. This approach has the benefit of providing a clear frame of reference to all stakeholders, using publicly available data, thus deemed preferable overall. Better still would be for NGESO to communicate the assumptions used for modelling the neighbouring countries like it did in its report "FES Modelling Methods 2019". The 2021 version of this document does not contain the same level of clarity as it simply states that the market fundamentals of the neighbouring countries were strongly inspired by reports from national electricity TSOs, national regulators and the ENTSO-E Ten Year Network Development Plan (TYNDP)". It should be noted that no market scenario is without shortcomings, hence some degree of disagreement will remain.
Disagreement with underlying assumptions	In Arup's view, organising a modelling workshop would mitigate the risk of disagreement on the outputs of the CBA directly linked to the inputs used. The workshop should focus on topics such as:

Stakeholder feedback	Arup's view
	- what FES (for GB), the national equivalent of the annual FES scenarios or TYNDP scenarios (for the other relevant countries modelled) to consider; and - some key assumptions, including commodity prices, weather, and how incongruencies between these should be addressed (e.g. interconnector capacities) or how to establish the interconnector baseline. Although we do not expect the workshop to reach consensus across all stakeholders, it would provide further transparency and an opportunity to debate the assumptions and reach a coordinated view for the scenarios.
Disagreement on the assumptions regarding capacity mixes	Arup finds that the approach followed at Window 2 is fit for purpose. The FES scenarios and TYNDP scenarios represent solid reference points. Both publications are submitted to several rounds of stakeholders' feedback before the final publication and are widely used in the energy industry.

Table 4 – Arup's View on Stakeholder Feedback Relating to the Modelling Approach

Stakeholder feedback	Arup's suggestion
BID-3 is not a suitable modelling tool	In Arup's opinion, power market models such as the BID-3 model can be considered a suitable tool, especially when integrated with welfare transfer impact analysis between stakeholder groups. Despite being a linear deterministic model, a wide range of deterministic inputs can be used to mitigate this issue. Some power market modelling tools, such as BID-3, have the capability to run grid expansion studies. Whether or not this functionality is used depends on the scenario development approached (i.e. exogenous capacity mixes extracted from industry publications or in endogenously calculated by the model).
Demand is considered inelastic	Certain market modelling tools have the capability to make some part of the demand price sensitive (e.g. EV, Demand Side Response).
Generator investments are assumed to be exogenous.	This aspect is inherent to taking the FES/ENTSO-E capacity mixes as an input, which in Arup's opinion is a reasonable approach. In the context of creating a completely bespoke scenario (outside of the FES/TYNDP scenarios), most market simulation tools can optimise the retirement of old units and the creation of new units over the forecasting horizon. This will endogenise the investment/retirement decisions in the modelling.
Use of stochastic data to model interconnector revenues	The current approach has run every scenario with 20 different weather patterns. The results and conclusions are based on the average of these scenario runs. As pointed out by Ofgem's consultant, although this gives a fair representation of the expected performance of the interconnector (on average over the lifetime of the asset), this performance could be significantly higher or lower in some years, depending on the out-turn weather conditions. In other words, although this approach is deterministic in nature, it covers a wide range of weather patterns, which mitigates the risk of creating a positive or negative bias in the evaluation of the economic value of an interconnector. A stochastic approach (also known as Monte Carlo simulation) would essentially aim to achieve the same goal in a different way. Instead of relying on a series of historical weather years, it would simulate as many weather patterns as required to obtain a robust average, which does not fluctuate much from one set of stochastic simulation to another based on a statistical distribution. However, there are pragmatic issues with this approach. Firstly, the simulation time can be significantly increased, especially if the number of draws required to obtain stable results is large. Secondly, and perhaps more critically, it is more difficult for stakeholders to replicate the results if compared to use specific historical weather years. In short, Arup's opinion is that the current approach is suitable, however it can be improved by (i) demonstrating statistically that the historical weather years considered cover a wide

Stakeholder feedback	Arup's suggestion
	spectrum of weather patterns and thus the average is robust; (ii) disclosing the weather years used in the simulation and (iii) ideally ensuring that stakeholder have access to these inputs.
Inclusion of ancillary services in interconnector revenues.	Arup agrees that interconnector revenues from the provision of ancillary services can be included in the SEW calculations. These can be co-optimised with wholesale market in market simulation tools (e.g. PLEXOS).
Modelling interconnector value within shorter trading time frames	In Arup's view, SEW can be modelled on an ID time frame in market simulation tools. As more intermittent RES generation capacity is deployed in the future, assessing interconnector value on this market can be valuable despite low historical evidence.
Implicit trading arrangements between the UK and the European Union (EU)	Two years after Brexit, there is a still a high degree of uncertainty revolving around the electricity trading arrangements between the UK and the EU. The traditional solution to treat such uncertainty is the elaboration of a sub-set of scenarios based on alternative trading arrangements than those assumed in the FES scenarios. However, this would significantly increase the complexity of the modelling exercise, effectively requiring running the market model for three additional scenarios (High, Base and Low). Therefore, Arup suggests revisiting this assumption for each application window based on the approach followed by NGESO when developing the FES scenarios.

Assessment of wider impacts

Arup found that the stakeholder's feedback on how Ofgem should assess the wider interconnector impacts identified was quite generic and high level. Whilst there was general agreement on the need to consider these impacts, practical suggestions on how to measure them were not provided.

In order to gain a better understanding of which indicators and methodologies can be used to better capture these wider impacts and improve Ofgem's assessment framework, Arup conducted a review of other relevant analysis and assessment tools. This is presented in the following section.

2.3. Review of alternative frameworks

Alongside the Ofgem assessment framework, Arup reviewed other relevant ones, namely:

- ENTSO-E CBA guidelines;
- National Grid's Network Option Assessment for interconnectors (NOA IC);
- the CION process, and
- the Green Book.

The first three are key frameworks used to capture the specific impacts of electricity transmission projects from both a technical and economic perspective. These are vastly used in the UK and in the EU, are subject to public scrutiny and offer a good starting point to help identify indicators and methodologies that can be used to improve Ofgem's assessment framework for interconnectors.

Arup also considered the Green Book, the guidance issued by the HM Treasury on how to apprise policies, programmes and projects in the public sector, to identify key principles and guidelines to develop a multi-criteria assessment framework.

Arup also considered whether to review the assessment frameworks applied by other EU energy regulators and other UK regulators, e.g. Ofwat. EU energy regulators are part of the Agency for the Cooperation of

Energy Regulators (ACER) and as such they rely heavily on the ENTSO-E CBA methodology, which, although developed by the TSOs, is approved by ACER as part of the TEN-E governance. The report therefore covers the CBA approach used by ACER members to approve interconnectors and projects of common interest.

In terms of the water sector, Ofwat also assesses the needs case for large enhancement projects through CBAs. Ofwat, however, is not particularly prescriptive to water companies on the modelling undertaken for the CBA. As the water networks are not interconnected and enhancement projects range from treatment plants to network schemes across different topographies, the modelling tools and requirements differ. Ofwat's assessment framework for large schemes is more focused on a process of gated assessment undertaken by the newly formed Regulators' Alliance for Progressing Infrastructure Development (RAPID). This process narrows down the number of projects and options for resolving a particular issue a water company faces by releasing more funding at each stage of the assessment for further analysis. We do not consider this approach to be appropriate for interconnectors who operate in an energy market dynamic.

2.3.1. ENTSO-E CBA framework

The ENTSO-E has developed a set of guidelines to run a CBA of European grid development projects. The latest CBA guidelines were published in March 2021.[13]

The CBA guidelines are a result of a well-established development and consultation process which considers feedback from European Member States (MS) and National Regulators before they are submitted to the official opinion of the ACER and of the European Commission (EC). The CBA guidelines are primarily used for the ENTSO-E TYNDP, the outputs of which are then used in EC's selection of Projects of Common Interest (PCIs). These are also be used as a source for national CBA by the various MS.

The CBA guidelines present a framework for the consistent assessment of a new project based upon three broad categories: benefit, costs, and residual impact indicators. Each category is composed of various individual indicators, as shown in Figure 1 below. The benefits category includes one of the most comprehensive and detailed lists of indicators, covering traditional SEW impacts as well as decarbonisation and system security impacts. It is worth noting that the latter impact category includes indicators related to system flexibility and operability, which ENTSO-E describes as "non-mature indicators that need to be further improved".

Further details on the ENTSO-E modelling approach, along with a description of each indicator, can be found in Appendix D

[13] 3rd ENTSO-E guideline for cost benefit analysis of grid development projects (windows.net)

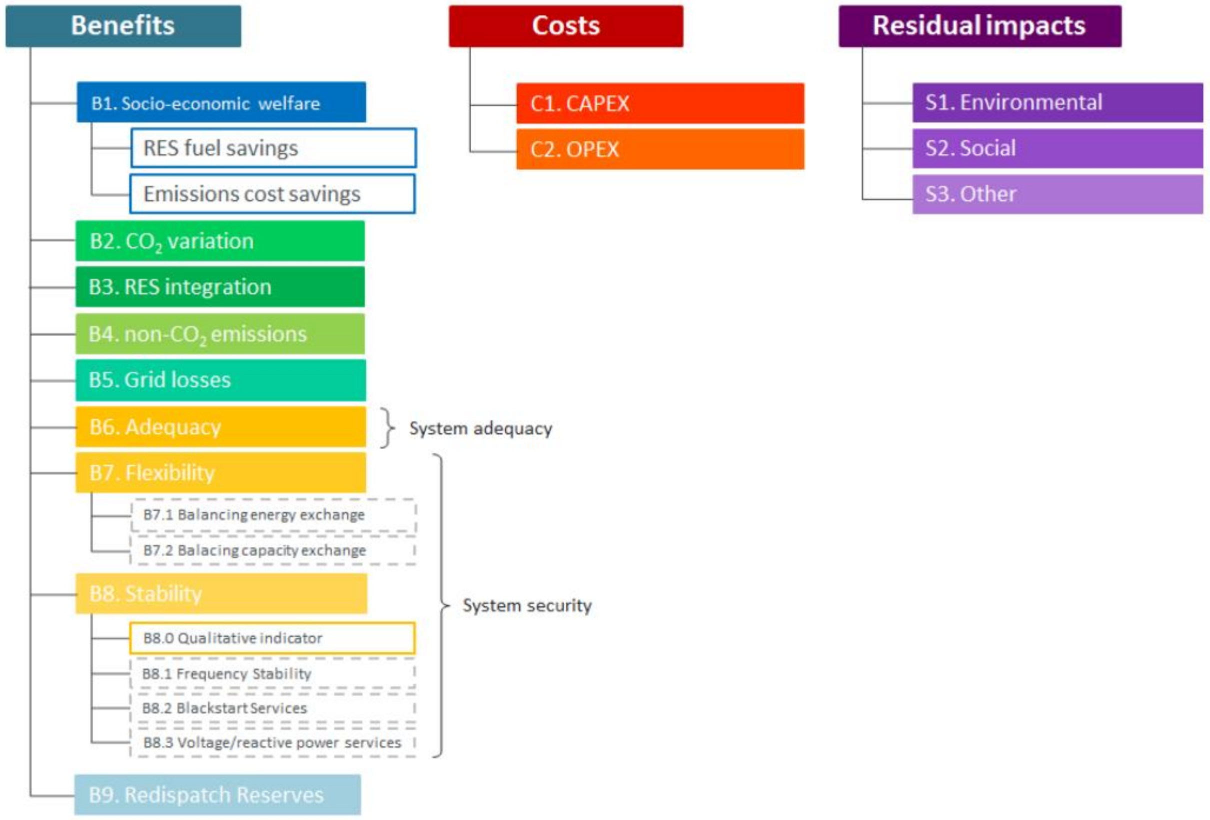

Figure 1 - Illustration of the project assessment framework categories under the ENTSO-E CBA guidelines. Dashed lines represent indicators that need further improvement

Source: ENTSO-E

Assessment of hybrid interconnectors

In 2022, ENTSO-E published the implementation guidelines for the TYNDP 2022 (the implementation guidelines). In the document, the assessment of hybrid interconnector (MPI) projects is treated for the first time.[14] Interestingly, ENTSO-E does not indicate the need to develop other benefit indicators in addition to those listed in the CBA guidelines in order to assess impacts of MPIs. This allows for a fair comparison between projects within the TYNDP framework.

However, whilst the application of indicators and their methodologies remains the same, ENTSO-E recognises that the CBA approach used to assess interconnectors and MPIs differs slightly. Factors such as the type of MPI model selected and market set up preferred can substantially impact the modelling of a project's impacts as they would affect both the transmission capacity available for cross border trade as well as the price differentials used to determine interconnector flows and overall SEW impacts.

Considering these complexities, ENTSO-E state that developers themselves should indicate which CBA approach to use based on their project's configuration, the other counterfactual considered, and the targeted market set up to limit the scope of the CBA analysis.

2.3.2. NOA IC

The NOA IC[15] is a study run by NGESO which identifies the optimal level of interconnection capacity in GB, (i.e. capacity that maximises the NPV of SEW in GB and the relevant connecting countries),

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[14] ENTSO-E defines hybrid projects as projects **"***which enables an interconnector function between bidding zones (either onshore or offshore) while simultaneously facilitating a client connection with a certain technology (RES or non-RES; generation, load or storage; AC (e.g. Kriegers Flak) or DC (e.g. North Sea Windpower Hub)).”* To avoid confusion, hybrid projects are referred as MPI projects throughout this document

[15] Network Assessment Option 2022

Attributable Constraint Savings (ACC) and Capex costs through a market and network assessment. [16] The framework assesses theoretical interconnector options to give the final optimal level, as opposed to assessing existing or future projects. The SEW is calculated by summing the following three categories:

- Consumer surplus – the impact of market prices seen by the electricity consumers;
- Producer surplus – the impact of market prices seen by the electricity producer; and
- Interconnector revenue or congestion rents – the impact of revenues between different markets.

ACC are the costs incurred to turn down generation to deal with the network constraints as a result of the new interconnection. The Capex costs include both the cost of the interconnection capacity and network reinforcements. Key drivers in the cost of building the interconnection capacity include the convertor technology, cable length and capacity of the cable. The NOA IC relies on standard costs produced by various industry bodies to estimate the capacity cost.

Along with the main factors (SEW, ACC and Capex), the NOA IC also analyses changes in carbon emissions and the use of RES. However, the latter two factors are reported solely to aid understanding of the potential impact to meeting GB's climate change goals, rather than to influence the optimisation process.

Similar to Ofgem's assessment, the NOA IC 2022 used a power market dispatch model (BID-3) to forecast SEW and ACC. The NOA utilises outputs of the National Grid's FES 2021 as model inputs (compared to the ad hoc scenarios used by Ofgem), including generation plant ranking orders and demand forecasts across Europe for each energy scenario. The optimisation process then involves maximising the value of SEW – Capex – ACC, by sequentially adjusting the interconnection capacities. As the time of capacity increase can affect the SEW and ACC values, timing combinations are also considered with each step. Therefore, the generated output will provide an optimal interconnection capacity based on the market combinations, along with a commentary on the ideal timings for this capacity increase.

2.3.3. CION process

The CION [17] process is a detailed network assessment that takes place upon the submission of a connection request from a new offshore generation or interconnector developers. The purpose of the CION is to evaluate transmission options and identify the overall efficient and economical connection location, onshore/offshore connection/transmission system/interconnector design. Therefore, the scope of this assessment is limited, focusing exclusively on a specific portion of project costs.

The process is coordinated by NGESO and involves collaboration between the developers and Transmission Owners (TOs) to assess the potential onshore connection options, the cost of the required transmission works, and the requirements for technical environmental, planning consent and deliverability issues associated with each connection point.

The connection options are analysed and short-listed for a CBA to be undertaken by NGESO. The developer or the TO provides NGESO with projected capital costs for each design and connection option, along with other data (e.g. wider system boundary capability impacts, capital cost phasing and Weighted Average Cost of Capital (WACC)).

The CBA provides, for each proposed connection point, a comparative assessment of the total project costs against the expected benefit to the consumers (equal to the constraint savings), ultimately reaching a recommendation of the most economic connection location. The constraint costs are simulated using a power market dispatch model through optimising generation and storage resources to meet consumer demand needs.

It is important to note that the CION document itself is a justification of the connection location, based on the output of the CBA analysis, which only considers the cost of the project against the associated constraint

[16] Arup notes that the latest version of the NOA does not include capacities related to MPI projects.

[17] Connection and Infrastructure Options Note (CION) Process Guidance Note

costs. Therefore, although it is a useful source for a project's constraint costs, its scope is quite limited in comparison the ENTSO-E CBA, which covers many more impact categories.

2.3.4. The Green Book

The Green Book, published by HM Treasury, is the UK Government's guidance on appraisal and evaluation. The guidance applies to Government policy and shapes the use of funding. It does not provide specific guidance for sectors or certain types of policy interventions. Instead, supplementary guidance has been produced by different departments which aligns with the Green Book, such as the Department for Transport's Transport Appraisal Guidance (TAG)[18] for transport-related policy interventions.

The Green Book has been considered as part of this review because it shapes Government policy interventions. It provides practical advice on appraisal and can augment Ofgem's approach to assess new projects. For example, the Green Book provides additional steps and decision points that, instead of creating more work, can in fact streamline the appraisal process by sifting options earlier for a more detailed CBA. The Green Book does this by suggesting the following appraisal steps, with each forming a decision point:

1. **Strategic Case:** set out case for change, i.e. what problem does it solve and SMART objectives;
2. **Longlist analysis:** variety of interventions tested against SMART objectives and case for change;
3. **Shortlist appraisal:** case models and social CBA used to appraise shortlist;
4. **Identify preferred option:** based on appraisal, set which options best balance costs, benefits, risks, and monetisable factors for best value for money; and
5. **Monitoring and valuation:** recognition that the policy decisions should continue to be assessed after they have been delivered, to inform better future decision making.

Currently the Ofgem approach focuses on the "shortlist appraisal" step. However, the earlier steps presented in the Green Book could be incorporated into the Ofgem model. These can be useful for early sifting to streamline the assessment and for capturing non-monetisable benefits that may be strategically important.[19]

Alongside guidance on how to structure an appraisal, the Green Book and supplementary guidance such as the TAG do provide useful resources for thinking about how to go about monetising benefits. Further, the TAG and other supplementary guidance such as BEIS valuation of energy use and greenhouse gas (GHG) emissions for appraisal [20] provide useful metrics for impacts such as health and GHG emissions.

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[18] Transport Analysis Guidance

[19] Arup notes that a potential caveat that may apply is the range of solutions that Ofgem is considering when appraising interconnectors. Under a typical Green Book approach, an interconnector proposal may be considered as a form of power supply upgrade alongside other potential options, such as, for example, onshore power stations or other renewable sites. Through the assessment framework considered in this document, Ofgem would select an interconnector project over other similar projects, rather than over a different type of project. Therefore, some thinking may be required as to how to best make use of a longlist.

[20] Green Book supplementary guidance: valuation of energy use and greenhouse gas emissions for appraisal

2.3.5. Comparison of the assessment frameworks considered

Table 2 compares the relevant frameworks considered with Ofgem's one. The ENTSO-E CBA guidelines stand out as one of the most comprehensive and relevant assessment frameworks, and they represent an excellent reference point to improve Ofgem's one. In fact, they include several technical /economic indicators and relevant methodologies to quantify and monetise the specific impact of electricity transmission projects, covering the wider categories that Ofgem wants to assess going forward, except for system operability and flexibility impacts.

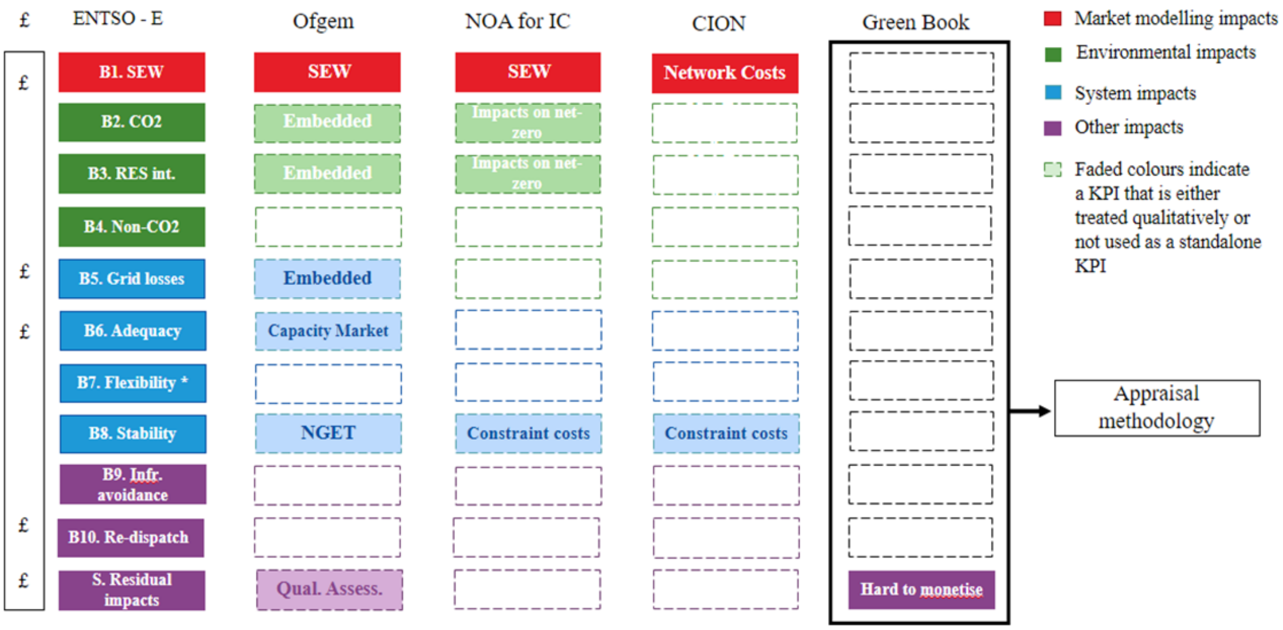

Figure 2 - Comparison of the assessment frameworks considered. Blank boxes represent indicators that are not considered in the corresponding framework, whereas faded boxes represent an indicator that is either treated qualitatively or not used as a standalone KPI.

These guidelines also benefit from being agreed upon by relevant stakeholders through a well-established public consultation process. Also, they are already widely used and familiar to developers and other European National Regulatory Authorities (NRAs).

Importantly, the theoretical scope of Ofgem's framework is only marginally more limited than the CBA guidelines, as they broadly consider similar impact categories. However, the former does not quantify as many categories as the latter, nor it treats them as standalone evaluation criteria. Compared to the other frameworks considered Ofgem's one is in fact more comprehensive.

The NOA IC presents some overlaps with Ofgem's assessment framework. Both assessments look at the impacts that interconnectors can have on SEW, constraints costs, changes in CO_2 emission and RES integration using a power market dispatch model. However, Ofgem's assessment is slightly more comprehensive as it also includes impacts on system operability and ancillary service costs. The two assessments also use the same type of model (i.e. power market dispatch) to determine interconnector flows. The key difference between the two frameworks is that the NOA IC looks to optimise a range of theoretical interconnection options based on the FES scenarios, rather than assessing specific interconnector projects.

The CION is a key source for constraint costs information that needs to be retained in Ofgem's assessment framework. It is worth noting that a power market dispatch model is used for the calculation of these costs. Theoretically, it would be then possible to integrate the outputs of the CION process directly into Ofgem SEW analysis, once the underlying scenarios, methodological approach used, and timings of the two analyses are aligned. However, developers sign connection agreements with NGESO before their submission for a C&F application, as securing a connection point is considered a key milestone in the initial development stage of an interconnector.

Finally, the Green Book does not include indicators or methodologies to assess impacts particularly relevant to energy projects, but it provides helpful guidelines on how to appraise public and regulated utilities spending from policy inception to delivery and monitoring through a multi-criteria assessment framework. This framework captures qualitative and quantitative impacts and may be an approach to consider for the assessment of interconnector proposals. The Green Book also provides suggestions on how to monetise certain benefit streams which are not currently monetised in the Ofgem framework and may prove useful in the future, as well as which hard to monetise impacts should be considered.

2.4. Summary of initial findings

Based on the review of Ofgem's assessment framework, Arup's initial findings can be summarised as follows:

- **The underlying structure of Ofgem's assessment framework can be considered broadly fit for purpose because its theoretical scope is relatively comprehensive.**
    - In fact, it already considers some of the wider impact categories identified during the interconnector policy review, namely system operability (through NGET's analysis), security of supply and decarbonisation (through the assessment of hard to monetise impacts), albeit in practice, this is less transparent.
- **The SEW analysis can also be considered fit for purpose.** Modelling tools, methodologies and decisions used are adequate and should be replicated in future needs case assessments
    - In this chapter, Arup has addressed the most relevant stakeholders' feedback and provided suggestions on how to improve the modelling, if necessary.
- **However, the assessment framework as a whole presents some shortcomings:**
    - Overall, Arup found a lack of depth in Ofgem's assessment and lack of clarity how these wider impacts feed into the IPA decision, as the framework primarily relies on the SEW analysis to reach a final decision.
    - This might be explained by the fact that most of the wider impact categories are considered only as part of the assessment of the hard to monetise impacts, rather than quantitatively. This means that it is not clear how much the impacts under other categories have influenced Ofgem's final decision in the past.
    - Importantly, the indicators that can describe quantitatively impact categories such as decarbonisation and security of supply are already embedded in the standard calculations required to determine SEW impacts. These can be extrapolated in order to create quantifiable, standalone indicators to provide more granularity in the assessment. Where necessary, additional indicators can be considered to further expand the level of detail of the assessment.
    - Additionally, because of the sensitive nature of some of the information considered and the differences in the modelling used to determine the value of system operability impacts and network cost compared to the SEW analysis, it was unclear how this information was used in Ofgem's decision making process.

Based on the review of other relevant assessment frameworks, Arup found that:

- **The ENTSO-E CBA guidelines are an excellent reference point to improve Ofgem's framework**.
    - They specifically assess the impacts of new electricity transmission projects from either a technical or economic point of view, providing a vast range of indicators and relevant methodologies for the quantification and, where possible, the monetisation of the wider impact categories Ofgem has decided to include in its framework. This applies particularly

for the indicators measuring the decarbonisation and security of supply categories, for which the calculations are standardise and already embedded in power market modelling analysis.

  - However, the guidelines do not offer valid indicators and relevant methodologies for the assessment of the system operability and flexibility categories, as those proposed by ENTSO-E are considered mature enough. In the absence of widely used and tested alternative indicators, NGET 2017 analysis can be considered a valid proxy to assess these categories.
  - Additionally, the guidelines only aim to provide a standardised way to determine the value of a set of indicators in order to directly compare projects. They do not offer a clear framework to combine all the indicators considered to inform a final decision, which is left to the NRAs themselves.

- **The NOA IC partly overlaps with and duplicates the analysis that Ofgem conducts under the C&F regime assessment framework.**
  - Ofgem and NGESO use a similar methodological approach to determine SEWs, RES integration and changes in CO_2 emissions due to interconnectors. However, the two frameworks address different modelling questions. The NOA IC looks at impacts linked of additional theoretical interconnection options, whilst Ofgem assesses the impacts of specific, real-life projects.
  - Given the above, the NOA IC could be utilised by Ofgem as a reference study to assess whether its IPA decisions are aligned with NGESO's analysis (e.g. whether projects approved for a C&F regime sit within the optimal interconnector capacity between specific countries as suggested by the NOA IC),
- **The CION process is a key information source for network costs and forecast constraint costs.**
  - It is a well-established and reliable process that determines project-specific cost information, clearly defining the roles of developers, TOs and NGESO.
  - Considering calculation of constraint costs is derived through an economic dispatch optimisation model, the output could potentially be directly integrated into the calculation of SEW impacts, noting that the inputs, scenarios and timings of the two analyses would necessarily have to be aligned.
- **Considering the two points above, Ofgem might consider making the FSO the party responsible for running the SEW analysis in the longer term.**
  - Arup notes Ofgem and BEIS's joint FSO April 2022 publication[21] indicated the new roles and duties that the FSO will have, including providing advice on request to Government and Ofgem to inform key policy decisions. As of today, NGESO already runs the analysis to determine interconnector impacts on SEW, system operability costs, decarbonisation through the NOA IC using the same modelling tools used by Ofgem. NGESO is also a key party to the CION process required to calculate network costs, and it was the party assessing interconnectors' impacts on system operability in Window 2. Depending on how the new roles will be defined and detailed, the FSO may be asked to run the whole IPA assessment in future windows.
  - Establishing the FSO as the party responsible for the analysis would remove the need for Ofgem to commission its own CBA, ensuring consistency in the analysis of interconnector impacts by using the same set of assumptions, modelling approach and tools. This would mean that all the outputs of the analysis required could be integrated to derive a single monetary value describing the overall impacts of new projects. This would also allow to tap into the FSO's modelling and analytical expertise and piggyback on well-established developers' relations and information gathering procedures such as the CION process.

[21] Future System Operator: government and Ofgem's response to consultation

Ofgem would necessarily maintain an oversight role, being responsible for the definition of the key aspects of the assessment framework and would remain the final decision maker at the IPA stage.

- **The Green Book can provide guidance on how to reach a decision based on a number of qualitative and quantitative indicators.**
    - The Green Book also proposes some useful methodologies for monetising some currently non-monetised impacts in the future, based on approaches that are recognised by the HM Treasury. The Green Book and its supplementary guidance, such as DfT's TAG or BEIS valuation of GHG, present resources that could also be useful references when attempting to monetise impacts.
- **The impacts of MPIs can be described through the same framework used to assess interconnectors.**
    - Arup agrees with ENTSO-E's suggestion that the intrinsic impacts of MPIs are already captured by the indicators listed in the CBA guidelines. Hence, a comprehensive enough framework for interconnectors can be used to assess MPIs too.
    - Similarly, Arup also agrees that the actual modelling of these impacts might differ compared to interconnectors because of the unique nature of these assets.

The following chapter describes in more detail the impact categories and indicators Arup suggests using in future assessments to measure a project's impact, indicating underlying methodologies and key considerations to account for when using them.

3. Proposed indicators for future assessments

Chapter summary:

Based on the findings describe in the previous chapter, Arup proposes a list of recommended indicator and methodologies to assess seven standalone impact categories, indicating which are the best placed parties to run the analysis and highlighting key considerations.

Arup suggests using the same indicators to assess the impacts of MPI projects, although the actual modelling required to measure some of these impacts will differ from that for interconnector projects. The key modelling consideration to take into account going forward are also highlighted in this chapter.

Table 5 - Summary of the Proposed Indicators, Responsible Parties and Information Required from Developers

Impact category	Indicator	Unit	Source	Party responsible for the analysis	Information required from developers	Change compared to W2
SEW	Consumers SEW	£m/y	SEW market modelling	Ofgem's consultant	Project information such as justification of technical design, cable route, connection location, technology used for cable and converter stations, capacity, voltage, loss factors and project costs	**No major changes** compared to Window 2. Arup suggests replicating the analysis conducted in the past and implementing the minor recommendations described in Table 3 and Table 4 of this document.
	Producers SEW	£m/y				
	Interconnectors SEW	£m/y				
	Total SEW	£m/y				
Network costs	Onshore works	£m/y	CION	Relevant TO	Cost information for selected connection option from CION	**No change**. The CION process should be used also in the future to assess this category.
System operability	Frequency stability	MW/h	Market and Network modelling	NGESO	Alignment with Grid Code ECC.6.3.19 GRID FORMING CAPABILITY	**No change**. The ancillary services analysis by NGESO can be used to measure the impacts of a new project under this category.
	Frequency response savings	£m/ MW/h				
	Voltage stability	MVar				
	Reactive response savings	£m/MVar				
	Black start	£m/y				
Flexibility	Balancing Market impacts	£m/y	Market and Network modelling	NGESO	No information required	**New standalone category**. The assessment of constraint costs provided by NGESO can be used to measure the impacts of a new project under this category.
Decarbonisation	CO_2 reduction (SEW)*	£m/y			No information required	

	CO_2 reduction (Societal value)	£m/y	SEW market modelling	Ofgem's consultant		**New standalone category**. Indicators and methodologies required to measure the impacts under this category can be based on the ENTSO-E CBA guidelines (indicators B2 and B3).
	RES integration (avoided RES spillage)*	MWh/y				
	RES integration (additional RES capacity)	MW				
	Overall decarbonisation	t				
Security of Supply	Cost of EENS	£m/y	SEW market modelling	Ofgem's consultant	No information required	**New standalone category**. Indicators and methodologies required to measure the impacts under this category can be based on the ENTSO-E CBA guidelines (indicator B6).
Hard to monetise impacts	Environmental impact	qualitative	Developer's IPA submission	Developers	As described in Table 7	**Minor changes.** Arup suggests maintaining this impact category, broken down in multiple indicators
	Local community impacts	qualitative				
	Noise/Disturbance	qualitative				
	Landscape	qualitative				
	Other impacts	qual/quant				

* Indicates indicators that contributes to the SEW impacts and should be reported separately to avoid double counting, as discussed in section 3.1.

3.1. Socio-Economic Welfare

Indicator description

SEW is defined as the sum of the short-run economic surpluses of electricity consumers, producers, and transmission owners.

Methodology

Arup recommends replicating the approach used by the Ofgem's consultant at Window 2 described in section 2.1.1 of this document. In Arup's view, it is comprehensive, and it captures the fundamental changes in welfare of the key stakeholders' categories. This approach is also aligned with ENTSO-E's 'total surplus' approach described in the CBA guidelines, which compares the producer and consumer surpluses for both bidding areas, as well as the congestion rent between them, with and without the project.

Importantly, the consultant included three additional elements affecting welfare, namely (i) changes in low carbon support payments, (ii) capacity market impacts, and (iii) interconnector revenue cannibalisation effects. These are described in Table 1 earlier in this document. In the 2017 report, these additional welfare drivers are captured by adding an extra step after the market simulation step. The consultant's approach processes the above drivers through an exogenous model (CARAMEL Light) which uses the output of BID3 to answer the following question: everything else being equal, how does a new interconnector impact the welfare of consumers, producers and interconnector owners in GB and a connected country? Arup recommends that these additional elements should be considered also in future assessments.

Changes in SEW are reported in pound sterling per year (£/yr) for each project, for a given scenario and study year. In addition to the overall SEW impacts, SEW impacts that are the result of integrating RES must be reported separately as follows:

- Fuel savings due to integration of RES.
- The costs related to the variation of CO_2 emission due to changes in the dispatch of the generation mix (see section 3.5 on Decarbonisation).
- The effects of RES integration on SEW due to the reduction of curtailment, which should be monetised and reported as lower short-run variable generation costs (see section 3.5 on Decarbonisation).

Similarly, SEW impacts arising due to cost related to expected energy not served (EENS) should be reported separately (see section 3.6 on Security of Supply).

The monetisation of these SEW impacts needs to be understood as separate information and must not be added to the SEW overall figure.

Monetisation

SEW is monetised and is given in £ (real terms)/year.[22]

Best party to run the analysis

Due to the complexity of the SEW analysis, Arup recommends Ofgem procure external specialist consultants for its delivery, as was done in previous assessments. This will allow Ofgem to tap into the consultant's analytical skills, expertise, resources and modelling tools. Arup considered the option of relying exclusively on analysis provided by the developers. Given the relevance of the SEW analysis to the overall outcome of

[22] It is worth noting that all indicators should be expressed as the annual average value across all the modelled years. If this calculation is too cumbersome, spot year values can be used instead. Where this is the case, this should be stated clearly. All monetised indicators should be expressed in Net Present Value based on guidance contained in the Green Book.

the IPA decision, and the need to assess the interactions between all applicant projects (rather than their individual impacts), using external consultants will ensure an unbiased and consistent treatment of all projects considered.

Arup notes that at Window 2 Ofgem required developers to submit their own analysis as part of their application to the C&F regime. It is not clear how this information was taken into account at the IPA stage. Considering the fact that Ofgem will base its decision on its own SEW analysis, the key underlying elements of which have been described in this document, Arup suggests making this submission optional, rather than mandatory. This would avoid unnecessary duplication of work for the developers.

If developers wish to, they can submit their own analysis as complementary information as part of their application. For example, developers could assess their projects' impact under specific ad hoc scenarios or using specific sensitivities, or assess specific impacts not captured in Ofgem's framework (see section 3.8 Other impacts). The methodologies, scenarios, and assumptions used should be justified if they differ from those used in Ofgem's analysis.

Whilst the developers' analysis should not determine the outcome of the IPA decision, it could provide valuable information for the modelling workshop. This in turn could inform Ofgem's own modelling. For example, Ofgem could agree to run specific sensitivities, create additional scenarios, or use specific data sets for certain inputs (e.g. weather years) that developers themselves have used. Ofgem should also present this complementary information in the relevant consultation documents, providing its opinion on which information was considered in the SEW analysis and the workshop, and why.

Finally, as was the case at Window 2, developers should provide the project's CAPEX and OPEX costs when submitting an IPA request, to be netted off the SEW impacts. Other relevant technical information regarding the project should be provided to Ofgem in alignment with its IPA submission requirements. This information will be specified by Ofgem ahead of each new application window and should include, but is not limited to, the justification of technical design, cables route, location of onshore connection points, technology choices, technical specifications (i.e. capacity, voltage, loss factors), project timelines, key milestones, risk management and strategy.

Additional considerations

Below are some additional points to consider for the SEW indicator:

- This indicator should be presented as a breakdown of the SEW impacts on the three key stakeholder categories, namely consumers, producers and interconnectors.
- As indicated above, this category of indicator is linked to the (i) Avoided CO_2 emission costs (SEW CO_2) and (ii) Value of Lost Load indicators.
- The geographical scope of the SEW analysis will be determined by the modelling capabilities of Ofgem's consultant. At a minimum, the analysis should cover GB, connected country, and prospective connected countries. Arup recommends that the scope is extended to a large part of continental Europe, if possible.
- Modelling the SEW indicator at the ID time frame will allow for a more detailed assessment of an interconnector's impacts on welfare and on the energy system. ID time modelling is a functionality that some power market modelling tools can deliver.[23] It is important to note, however, that this would increase the running time and complexity of the model, as both DA and ID time frames need to be simulated for each year, different weather assumptions and scenarios considered. In addition to this, several weather years need to be simulated.
- The SEW indicator is monetised. As such, it could be considered as a pass/fail indicator in the instance that the overall SEW value (i.e. cumulative net SEW of GB and the connected country, at minimum) is negative. It would, however, be important to consider the threshold at which a project is disqualified: it is conceivable that a project scores a slightly negative SEW but offers clear

[23] See PLEXOS interleaved mode. This mode is used to model the transition from the DA and the ID time frame.

unmonetized benefits in other areas. For projects scoring positive SEW, the suggestion is to perform a comparative grading.

- Arup understands that NGESO is using a single modelling tool to perform market simulation and grid simulation. There is potential synergy which can be exploited by having a single party performing both types of analysis in the future.
- A sensitivity analysis on the planned start date of the interconnector should be considered to understand the impact project delays might have.
- Arup has provided a list of other important modelling considerations in Appendix F.

Missing welfare drivers

As covered in section 2.1.1, some changes in welfare were not considered in SEW analysis run by Ofgem's consultants for Window 2. Arup recommends treating these as separate, standalone impact categories, where possible, as indicated in Table 6 below.

Table 6 - Missing Welfare Drivers in Window 2 of SEW Analysis Conducted by Ofgem's Consultants

Missing Welfare Driver	Section of the report this is discussed
Changes in network reinforcement costs, balancing costs, and other network related costs	See section 3.2 and 3.4. on Network Cost and Flexibility, respectively.
Improved security of supply	See section 3.6 on Security of Supply
Access to lower cost ancillary services, balancing services and other network operation costs	See section 3.3 and 3.4. on System Operability Impacts and Flexibility, respectively.
Bringing enhanced competition and liquidity to the connected markets	Given the liberalisation of electricity generation in GB and connected countries, significant competition already exists. This can be demonstrated by the merit order curve. As the energy network decarbonises, further generators/interconnectors will enter the market to meet the increasing electricity demand. It is therefore highly unlikely that interconnectors would have a significant impact on the overall number of market participants going forward or require a monopoly power test. Arup would not recommend measuring competition between GB generators and generators in connected countries, as long as the consumer and producer benefits are already captured in the SEW. This risks opening up political, rather than economic questions, which are part of Ofgem's duties.
Additional environmental benefits	See section 3.8 on Residual Impacts
The ability of interconnectors to enable the sharing of generation capacity across market borders which, in turn, off-sets the need for new capacity in one market	See section 3.6 on Security of Supply
Changes in payments for ancillary and balancing services (either by access to foreign ancillary and balancing services markets or by displacement of local providers)	See section 3.3 on System Operability Impacts and section 3.4 on Flexibility impacts
Reduction in producer revenues from the capacity market mechanism through direct displacement in the auction by the interconnector assessed	Not Treated. The overall value of this element is likely to be minimal.

Missing Welfare Driver	Section of the report this is discussed
Revenues from additional rescheduling of interconnectors in ID time frames	Arup suggests modelling the SEW at the ID time frame level.
Revenues from providing TSO to TSO, ancillary and balancing services between markets	This is the ENTSO-E approach to measuring flexibility. Arup would not recommend measuring this impact as the ENTOS-E approach relies on platforms that are not yet fully operational.

3.2. Network costs

Indicator description

Network costs cover the onshore works required to connect the project to the national transmission system as well as the wider reinforcement costs.

Methodology

Arup recommends for this information to be sourced from the CION. The CION uses a well-established process and methodologies approved by the industry to assess network costs. As described in section 2.3.3, the CION aims to identify the most efficient and overall economical connection location for a new project.

The customer (IC developer) applies directly to NGESO, who in turn makes an application to the relevant TO, depending on which transmission network the project will connect to. The TO designs the onshore connection and calculates the expected cost by carrying out system studies, engineering designs, a cost schedule, and a work programme. Due to the fact the interconnector developer must have a connection agreement in place to apply to the C&F regime, the onshore connection cost information can be lifted out of the CION and provided as part of the application.

Monetisation

This indicator is monetised by definition and should be expressed in real terms.

Best party to run the analysis

The relevant onshore TO. The relevant TO will be party to the CION process and will have the most accurate and up to date network data and models. Developers would need to provide the costs of the preferred connection option when submitting an IPA request, to be netted off the SEW impacts by Ofgem's consultants.

Additional considerations

At Window 2, connection costs information was not published due to the commercial nature of the information. Arup recommends publishing at least the results of future assessments of network costs in order of magnitude to improve the overall transparency of the assessment.

3.3. System operability impacts

System operability impacts describe the range of indicators that characterise and monetise the benefits a new project could provide to the GB power system through the provision of ancillary services. These services are procured by NGESO from generators and interconnector owners to support the electricity system during a foreseeable but unexpected event, consistent with the security of supply requirements.

Arup reviewed the methodology used in the NGET 2017 analysis, described in section 2.1.2 of this document, and found it fit for purpose. Considering the complexities linked to quantifying and monetising ancillary services, NGET's methodology represents a good proxy for these impacts. The approach described in the following sections is consistent with that methodology.

It is envisaged that the methodology will remain broadly consistent when applied for future application windows although the analysis tools, models and sensitivity parameters may vary to reflect the latest industry tools and methods. Arup engaged with NGESO who confirmed that this aligned with their view.

To improve NGESO's analysis of the system operability indicators, developers can provide information regarding the ability of the project to meet Grid Code ECC.6.3.19 GRID FORMING CAPABILITY, if applicable.[24]

When assessing these impacts, two important considerations should be taken into account:

- Some ancillary services are mandatory and defined in the Grid Code. Others are additional commercial services that a generator or an interconnector can decide to bid for. At present, there is no mandatory requirement for interconnectors to provide ancillary services in the Grid Code. This means that the impacts assessed under this category would not materialise unless the project considered decides to provide all relevant commercial ancillary services. Despite the above, Arup believes it is important to include these impacts for the purposes of the framework, as this would give an indication of additional potential benefits a project could deliver.
- Arup notes that NGET used FES scenarios to ensure consistency across the entirety of the analytical work it conducted in its role of SO at that time. For similar reasons, NGESO confirmed it would use FES scenarios to calculate a project's system operability impacts. Using the same FES scenarios for the calculation of SEW impacts would increase the overall consistency of Ofgem's needs case assessment process.

Unless interconnector revenues are co-optimised in the modelling, it is not recommended to add the monetised value of these impacts to the results of the SEW analysis, but to treat them as a standalone category showing additional potential benefits on top of the SEW analysis results. In order to integrate the results of the SEW and system operability impact modelling, Arup would suggest NGESO and Ofgem work together to enhance the alignment and consistency of the assumptions and inputs used in future analysis.

Finally, it is worth noting that at Window 2, for all the indicators listed in this section the outputs of NGET's analysis were redacted due to the commercial nature of the information contained. Arup recommends publishing at least the results in order of magnitude to improve the overall transparency of the assessment.

3.3.1. Frequency response

Changes in system frequency result from the real-time difference between system demand and total generation. The increasing connection of RES to the system reduces system inertia, which along with greater variation in supply and demand, results in system frequency becoming more volatile. Frequency response (FR) is the ability to react to these changes through various sources including generation, demand, and interconnectors.

Interconnectors with HVDC VSC technology are able to provide some level of FR, regardless of whether the IC is importing, exporting or in a net zero state, without the cost of repositioning. HVDC VSC type interconnectors can provide two types of FR, primary response (PR) and high response (HR). PR is required when the frequency is low, and conversely, HR is required when the frequency is too high. Interconnectors are beneficial as they can rapidly change their power output to respond to system frequency.

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[24] GC0137: Minimum Specification Required for Provision of GB Grid Forming (GBGF) Capability (formerly Virtual Synchronous Machine/VSM Capability). This modification seeks to implement a minimum specification for generators wishing to offer VSM capability – in that the affected plant responds more like traditional plant. Such plant would react to unplanned events/faults in a manner which does not result in a severe drop in frequency, allowing for balancing and response services to correct the drop in frequency in a more timely and predictable manner.

Methodology

Firstly, the difference in average FR costs between primary and high mandatory prices, compared to commercial costs, are calculated over a historical timeframe. Interconnector import/export profiles are then generated using a market model, to provide an indication of how the interconnector will operate over time. This is done by taking the unconstrained dispatch for each interconnector in turn, for each of the studied years, whilst considering different FES scenarios.

System FR requirements are calculated utilising inputs such as the largest loss, system-wide demand, and system inertia. Loading levels are applied to each interconnector, equal to different proportions of the total installed capacity, and their financial savings are calculated.

Monetisation

Monetary value based on the cost of different frequency response products, based on how long the ESO require the service, and how much frequency response is needed/.
The frequency response payment saving = MW and MW/h (£/MW/h).

Best party to run the analysis

NGESO. In Arup's opinion, NGESO is the best party to calculate these impacts, as it holds the relevant data, analytical expertise and deep understanding of the energy system required for the analysis.

Additional considerations

The cost for provision of the mandatory levels of FR from interconnectors should be considered more broadly alongside the cost of commercial services for interconnectors and other generators by industry to help achieve further market efficiencies.

3.3.2. Reactive power

The system's voltage levels are controlled through the injection and absorption of reactive power. The system's availability to provide reactive power is decreasing due to the closure and reduced use of conventional power plants, such as coal and gas-fired power stations. The reduced access to reactive response, therefore, reduces the system's ability to control voltage. There is also an increasing need to absorb reactive power due to a decrease in demand on distribution networks and reducing power flows across the transmission networks.

Interconnectors are designed with inherent dynamic reactive power and voltage control. HVDC VSC technology allows interconnectors to provide this reactive power support without the need to install shunt capacitors or reactors. However, system reactive power requirements are locationally specific, hence an interconnector can only provide these voltage stability benefits if it is connected to an area that requires such support.

Methodology

Pre-fault voltage studies

Pre-fault voltage studies are conducted to compare the difference in the reactive compensation requirements (Mvar) of the base case (with no interconnectors), compared to when the interconnectors are incorporated into the network. To explore the range of reactive power support, the interconnector dispatch levels are modelled at different proportions of their full capacities.

As previously described, reactive power requirements vary by location, and therefore the studies focus only on the area surrounding the planned connection location. The substations included in the voltage studies are within a limited substation range of the connection point.

Network Assumptions

The voltage studies use summer minimum morning demand data, as this presents the limiting factor when demand is low, few generators are in operation, and system frequency tends to be high. It is also assumed that all generators are dispatched as per the data in the FES scenarios.

Associated savings

Once the additional reactive compensation requirements have been determined through the voltage studies, the cost of providing this difference can be calculated. It is assumed that in the absence of the interconnector, the reactive compensation requirements would need to be provided through the supply and installation of shunt reactors or static synchronous compensators (STATCOM). Therefore, the reactive power compensation provided by the interconnector is measured by the investment savings.

Monetisation

Monetary value based on the avoided costs required to install additional equipment to meet reactive compensation requirements. Reactive compensation savings = Mvar (£m/MVar).

Best party to run the analysis

NGESO. In Arup's opinion, NGESO is the best party to calculate these impacts, as it holds the relevant data, analytical expertise and deep understanding of the energy system required for the analysis.

Additional considerations

The locationally specific nature of voltage requirements means that not all interconnectors will be able to provide this benefit.

3.3.3. Black Start

Black Start and restoration services are required to re-energise the network in the unlikely event of partial or total shutdown. These services are typically provided by large synchronous generators located across GB to allow the whole network to be efficiently re-energised if required.

Interconnectors with VSC technology can offer Black Start services at an economic cost and with fast restoration times, because they can access generators in a non-blacked out area. Interconnectors can also improve the system's resilience by providing access to a greater diversity of fuel sources.

Methodology

The current Black Start strategy involves the country being divided into 6 zones, with each containing at least 3 black start plant. These block zones are restored independently and then joined up until the whole network is re-energised. This requires generation to match demand in the local areas, whilst also maintaining voltage and frequency requirements. Interconnectors are able to provide Black Start services commercially in the GB ancillary services market.

This analysis assumes the following:

- There are no materially new additional capital costs associated with VSC interconnectors providing Black Start services.

- The zonal contracting strategy reflects the latest NGESO market approach.

Monetisation

Monetised value based on NGESO's estimated costs of contracting Black Start services. Black Start savings = MW (£m/MW)

Best party to run the analysis

NGESO. In Arup's opinion, NGESO is the best party to calculate these impacts, as it holds the relevant data, analytical expertise and deep understanding of the energy system required for the analysis.

Additional considerations

It is important to maintain diversity of generation in each Black Start zone. Where an interconnector is already providing Black Start services in a zone, there may be materially diminishing benefits for additional interconnectors providing this service.

3.4. Flexibility - Thermal constraint savings

Indicator description

Flexibility refers to the capability of an electricity system to provide the system balancing needs where there is a high penetration of non-dispatchable electricity generation**.** System flexibility is the ability to adjust supply and demand, during normal system operation conditions, to achieve that balance, and to help manage locational constraints on the network.

Interconnectors are expected to play a pivotal role in enhancing the capability of power systems to cope with more non-dispatchable electricity generation. By balancing these RES generation fluctuations across wider zones, the risk caused by intermittent RES generation decreases as weather patterns between interconnected countries are not perfectly correlated. Furthermore, transmission capacity provides a form of flexibility by pooling together available flexible units that can be shared between different control areas.

Whilst the System Operability indicators focus on the provision of ancillary services, the Flexibility indicator focuses on the impact a project can have on Balancing Mechanism costs. This section provides more details on how these two aspects relate to each other.

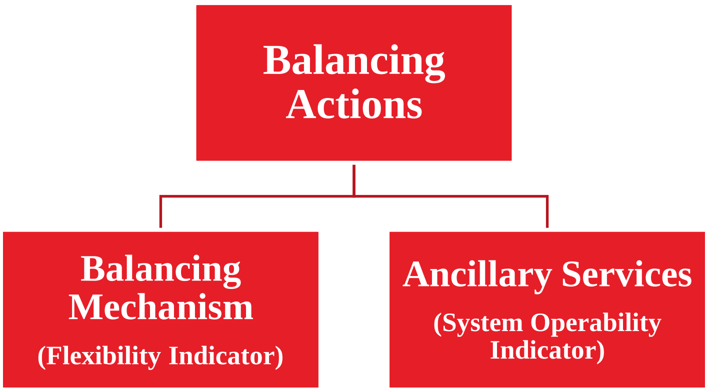

Figure 3 - Distinction between flexibility and system operability indicators

Balancing Actions are actions taken by NGESO to ensure that demand and supply match on a minute-by-minute basis. The figure above focuses on the two key balancing actions which are captured by, and included, in this assessment framework. The Balancing Mechanism is one of the tools NGESO uses to balance electricity supply and demand close to real time. Where NGESO predicts that there will be a discrepancy between electricity production and demand during a certain time period, they may accept a 'bid' or 'offer' to either increase or decrease generation (or consumption). NGESO uses the Balancing Mechanism as the primary means carry this function out and to balance the system.

Balancing actions can also be carried out through Ancillary Services. Some of this is procured in separate markets through auction. These include services for short-term reserve, operating reserve, and frequency management, among others. The balancing mechanism takes place continuously and ancillary services are only called on when and where a system operability need occurs.

Similar to the calculation of system operability impacts, Arup believes NGESO is the best party to assess the impact a new project can have on flexibility. Arup have reviewed the methodology used in the NGET 2017 analysis, and found it is fit for purpose. As such, the methodology described here is consistent with the one used by NGET. Similarly, the same considerations regarding the evolution of the methodology used for future application windows (i.e. beyond Window 3), the use of FES scenarios and the publication of commercially sensitive information apply to this impact category as well.

Methodology

Costs that the ESO incur on the balancing mechanism can be described as constraint management costs. The methodology used can be summarised as follow:

1. Key inputs are collected from FES scenarios and associated NOA optimal reinforcement paths.
2. A market modelling tool is used to forecast constraint costs by optimising generation and storage to meet consumer demand. The value of constraint costs depends on where the interconnector is connected in the network and the local generation mix, network topology and power flows, and thus the likely magnitude of thermal constraint.
3. Pan-European market unconstrained dispatch is calculated first, followed by the modelling of GB's network constrained redispatch. Each analysis is first run with the proposed interconnector (IC) and then with a counterfactual (no IC). The difference between the IC run and the counterfactual run will enable to calculate the delta in constraint costs due to the addition of the IC. The total constraint costs are the combined total of all bids accepted (i.e. offers to buying energy by decreasing generation or increasing consumptions), and all offers accepted (i.e. offers to sell energy by increasing generation or decreasing consumption).

Monetisation

Relative constraint saving/cost = £m

Best party to run the analysis

NGESO. NGESO has the most thorough and up-to-date information and tools. NGESO is responsible for the balancing mechanism, which is what this analysis focuses on. No additional information is required from developers for the analysis of the flexibility indicator.

Additional considerations

Price differentials between the interconnected countries impact power flows, as power usually flows from a low-price area to a high price area, which also generally reflects the flow of power from a low to high area of demand, and therefore the congestion of the network. As such, changing energy prices can have significant effects on the impact of the additional interconnector.

3.4.1. Decarbonisation impacts

3.4.2. CO_2 reduction (SEW)

Indicator description

This indicator estimates the change in CO_2 emission due to a new project being connected. This indicator is of relevance as the UK power sector is a significant contributor of CO_2 emissions and grid development can help modify the level of CO_2 emissions. The avoided CO_2 emission costs can be extracted from market simulations by multiplying the difference in CO_2 emissions (in t) by the cost of CO_2 (in £/t). These costs can be seen as the costs of CO_2 as linked to the costs created by the carbon markets of the countries modelled.

Methodology

This indicator can be calculated using market modelling commissioned by Ofgem or by the market modelling run by the ESO. It is a widely used, simple and standard methodology that reports the impact of changes in the generation mix dispatch on CO_2 emission. For this indicator, the CO_2 emissions will be calculated with and without the project.

$$= \sum_{k=1}^{n} \left(CO_2 \text{ emission}_k^{Base} - CO_2 \text{ emission}_k^{Interconnector} \right) * CO_2\ Market\ Price_k \left(\frac{£}{tonne}\right)$$

where n represents the number of years over which the analysis is conducted.

Monetisation

This indicator should be reported in real monetary terms.

Best party to run the analysis

Ofgem's consultant, as part of SEW analysis. This will ensure consistency. No additional information is required from developers for the analysis of this flexibility indicator.

Additional considerations

The monetary value of the indicator is part of the SEW calculations already estimated by the market modelling tool. This indicator should be reported on separately to ensure better visibility of the CO_2 emission impact. As such, the value of this indicator is not meant to be added to the value of the SEW indicator. With this in mind, the total SEW can be expressed as:

$$SEW_{Total} = SEW_{CO_2} + SEW_{rest}$$

3.4.3. CO_2 reduction (Societal value)

Indicator description

In its CBA guidelines, ENTSO-E distinguishes between the price of CO_2 that is imposed on carbon-based electricity production (i.e. the obligation to purchase CO_2 emission rights under the Emissions Trading Scheme(ETS)) and the societal cost of CO_2. The societal cost of carbon can represent two concepts:

- The damage cost, or the total net damage of an extra metric ton of CO_2 emission due to the associated climate change.
- The avoidance cost (shadow price) that is determined by the climate goal under consideration. This can be interpreted as the willingness of society to pay for imposing the goal as a political constraint.

The avoidance cost approach is typically preferred to guide investments. ENSTO-E developed this indicator in acknowledgement that the cost of CO_2 imposed on electricity producers does not necessarily reflect the total societal value of reducing CO_2 emissions nor does it give the necessary incentive to reach environmental goals of a given country. It is therefore important to have an indicator that captures the cost that CO_2 emissions have on society.[25]

Methodology

As the previous indicator, calculations to determine the variation of CO_2 emissions with and without a project can be based on the market modelling commissioned by Ofgem or by the market modelling run by the ESO. However, it is important to remember that part of the monetary impacts from CO_2 emission variation is already computed within the SEW calculations (using the market cost of CO_2) and which is already captured by the indicator above (i.e. CO_2 reduction (SEW)).

Hence, this indicator (i.e. CO_2 reduction (Societal value)) should only report the additional part of the CO2 benefit that is not already captured by the market value of CO_2. Consequently, the formula for this indicator is the following:

$$= \sum_{k=1}^{n} (CO_2 \text{ emission}_k^{Base} - CO_2 \text{ emission}_k^{Interconnector}) * (CO_2\ Societal\ cost_k - CO_2\ Market\ Price_k)(\frac{£}{tonne})$$

where n represents the number of years over which the analysis is conducted.

Monetisation

This indicator can be monetised using the Green Book's values of societal cost for CO_2, published alongside the supplementary guidance for the valuation of energy use and greenhouse gas emissions.[26]

Best party to run the analysis

Ofgem's consultants, as part of SEW analysis. This will ensure consistency. No additional information is required from developers for the analysis of this flexibility indicator.

Additional considerations

It is important to note that the societal value of carbon is not used in the market modelling per se, where the dispatch of generator is optimised based on the market cost of CO_2 (i.e. the price of CO_2 under the relevant ETS). Therefore, the monetary value of this indicator is not part of the SEW calculations already estimated

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[25] It can be argued that because the energy sector is subject to the ETS, any reduction in CO_2 resulting from the construction of a new project would allow the ETS participants to save unused allowances for future need or sell them to another installation that is short of allowance. Consequently, the society does not see the effect of this reduction because it is either postponed in time or used to allow another sector to pollute more (the so called 'waterbed effect'). Based on engagement with ENTSO-E, it is Arup understanding that this is issue will be addressed in the ongoing EU ETS revision following the Fit for 55 package. Moreover, Ofgem's assessment of a new interconnector or MPI project is specific to the electricity sector. Therefore, it remains relevant to measure the impact such projects can have on emissions within the energy sector, whilst considering how this would affect other sectors under the ETS would be out of scope. Finally, given the time horizons of Ofgem' assessment, it can be fairly assumed that society will in fact see the net benefits of CO_2 reduction from a new project.

[26] Data tables 1 to 19: supporting the toolkit and the guidance, Table 3.

by the market modelling tool, and it should be reported on separately to ensure better visibility of the CO_2 emission impact on society. As such, the value of this indicator is not meant to be added to the value of the SEW indicator.

3.4.4. RES integration

This indicator provides estimates for the additional RES available to the system as a result of the project. The need to decarbonise the energy system in order to meet net-zero means it is fundamental to understand how a new project can support the deployment of RES.

Depending on the type of project assessed, this indicator can be expressed by two different sub indicators.

Avoided RES spillage

This sub-indicator applies to all projects (i.e. directly connecting RES or not). It is measured as a capacity-based indicator and expressed in MWh. It should demonstrate the amount of additional RES energy in the system that can occur due to the reduction in congestion as a result of a change in the generation dispatch.

Its value can be extracted from the calculation of SEW impacts and is computed as the additional yearly RES energy, reduced by the additional dumped energy in the system resulting from the addition of the project:

$$Additional\ \mathrm{RES} = \mathrm{Eproject} + (\mathrm{Edumpwithout} - \mathrm{Edumpwith})$$

Where:

- $Eproject$: the yearly energy produced by the connected RES source(s)
- $Edumpwith$: the yearly dump energy with the project included
- $Edumpwithout$: the yearly dump energy without the project included

Additional RES capacity

This sub-indicator applies only to projects directly connecting RES generation such as, for example an offshore wind farm (OWF) through an IC-led MPI project. It is expressed as the capacity of the integrated RES, in MW.

Best party to run the analysis

Ofgem's consultant as part of the SEW analysis. This will ensure internal consistency because the SEW analysis model (market modelling tool) already outputs these results.

Additional considerations

The monetary value of the avoided RES spillage indicator is part of the SEW calculations provided by the market modelling tool. This indicator should be reported on separately to ensure better visibility of the impact on security of supply.

3.4.5. Overall decarbonisation

Indicator description

Stakeholders stressed the importance of defining a robust methodology to account for changes in carbon emissions over a wider geographical remit and to estimate the variation of carbon intensity of the electricity supplied to GB across interconnectors.

However, the assessment of the actual carbon intensity of the electricity traded on a half-hourly basis is a complex exercise and it would be limited only to the countries hosting the project, not capturing the impacts of an interconnector can have on the decarbonisation of other neighbouring countries.[27] Therefore, there is the need to create an indicator which assesses the overall change in CO_2 across a wider geographical remit.

Methodology

- Consider reporting CO_2 change beyond GB. At a minimum, extend geographical remit to GB plus the country interconnected to the GB Power System. The wider the geographical coverage, the more robust the output of this indicator.
- Step 1: Base run of the market model without the interconnector. Report cumulative CO_2 emission up to 2050 in GB and in the country which is connected to GB via the interconnector (and other relevant neighbouring countries, if feasible).
- Step 2: Repeat market simulation with the interconnector. Compare the cumulative CO_2 emission of GB and the other country (or countries) with the base run.

Monetisation

Non monetised. Indicator expressed in t.

Best party to run the analysis

Ofgem's consultants as part of SEW analysis.

Additional Considerations

It may be possible to follow the same approach and extend the remit of this indicator to CO_2 equivalent emissions. [28]

3.5. Security of supply

3.5.1. Cost of Expected Energy Not Served

The ability to meet demand is the ability of a power system to provide an adequate supply of electricity to meet the demand at any moment in time. This risk can be captured by measuring the EENS. EENS is defined as the energy which is expected not to be supplied due to insufficient resources to meet demand needs in a given zone and during a given time period. Interconnectors are expected to help adequacy by pooling the risk of loss-of-load, whilst at the same time, pooling generation capacity to mitigate the risk. The benefit of adding an interconnector to a power system can materialise through a decrease in EENS volumes. When only one country is facing a loss of load, a new interconnector can help to import more, thereby reducing EENS.

The adequacy benefit of an interconnector can be assessed by calculating the reduction of EENS volume (installed capacity remaining constant) with and without the interconnector.

Methodology

- Run analysis with a wide range of weather patterns (at least 20 weather years)

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[27] The impact of interconnectors on decarbonisation

[28] A carbon dioxide equivalent or CO_2 equivalent, abbreviated as CO_2-eq, is a metric used to compare the emissions from various greenhouse gases on the basis of their global-warming potential (GWP), by converting amounts of other gases to the equivalent amount of carbon dioxide with the same global warming potential. An example of this is methane, which has a greater global warming impact than CO_2

- Compare the EENS between the base run and the run with the interconnector connected.
- Quantitative measure: EENS avoided is given in MWh/year

Monetisation

- Multiply the EENS reduction by the Value of Lost of Load (VoLL).
- VOLL is a monetary indicator expressing the costs associated with an interruption of electricity supply.

$$\text{Cost of EENS } (£) = \sum_{k=1}^{n} (EENS_k^{Base\ Run} - EENS_k^{Interconnector\ Run}) * VoLL(\frac{£}{MWh})$$

- Where n represents the number of years over which the analysis is conducted.

Best party to run the analysis

Ofgem's consultants as part of SEW analysis.

Additional considerations

The monetary value of this indicator is part of the SEW calculations provided by the market modelling tool. This indicator should be reported on separately to ensure better visibility of the impact on security of supply.

3.6. Hard-to-Monetise impacts

There are several impact areas that carry value but are difficult to monetise. This is because they have less tangible societal value or no clear market value, i.e. we cannot readily buy or sell them. There are similar impacts that have been monetised in appraisal frameworks, such as CO_2 equivalent for climate change or travel time for transport. The Green Book sets out potential approaches for going about monetising impacts that could be used in the future.

The suggested additional impacts categories are described in Table 7 further down. Each is likely to orientate towards negative impacts as the construction and operation of interconnectors causes disturbance, be that to the environment, landscape, noise pollution, or local assets (including roads and services). These may not bolster the value for money case of a project but will ensure transparency around potential project concerns. Hard to monetise impacts are important to capture because they can influence whether an interconnector proposal is successful when considered against planning and environmental policy. Ofgem does not advise on planning and environmental policy but does have a remit to prioritise consumer and public good. As such, Ofgem should have sight of any potential concerns that may be of concern to the public to enable Ofgem to consider all impacts of delivering a new interconnector.

For Ofgem's assessment framework, a more practical qualitative approach would be the use of red-amber-green (RAG) ratings. This provides a simple and transparent tool to assess proposals, while remaining relatively high-level. This high-level approach also considers the lack of detail that is likely to be available to developers when submitting their C&F application to Ofgem at the IPA stage. This is not intended to align with Multi-Criteria Decision Analysis (MCDA), or Multi-Criteria Analysis (MCA) as described in the Green Book because this is not intended to inform decision making. Instead, the approach will signpost potential concerns, without creating extra hurdles for Ofgem and developers, that are likely to be considered at planning and environmental policy stages.

Methodology

Table 7 sets out the hard to monetise impacts which will be assessed using RAG ratings. The RAG rating should measure the impact areas individually and they should not be ranked against one another. The purpose of the ratings is to flag concerns that may need to be addressed at a later stage, such as through the planning application or environmental impact assessment. The RAG ratings are defined as:

- Red: a significant concern or impact has been identified that will require further investigation at the planning and environmental policy stages.
- Amber: a minor concern or impact has been identified that may require further investigation at the planning and environmental policy stages.
- Green: no concern or impact has been identified.

The RAG rating will be assigned based on information that can be readily supplied from other parts of the submission. The methodology for each of the impact areas is set out in Table 7. If no information is available, then no RAG rating should be provided, but the risk should still be identified to allow for investigation when more information becomes available.

Table 7 - List of Hard-to-Monetise Indicators

Impact	Definition	Information the developer should provide	Assessment Approach
Environmental Impacts	Site specific impacts that concern the ground and soil, waterways, the air, flora and fauna, or other environment impacts. Impacts due to site changes to accommodate IC infrastructure should be reported on as well as impacts during construction and maintenance.	The assumption is that a site and a design has been proposed, and drawings have been provided. Based on the site location, a drawing should be provided from the planning policy map. This can be accessed online via the relevant Local Authority website. The planning policy map will include environmental designations that will indicate potential environmental impacts. Any relevant information that may support a RAG rating should be provided. This may include initial site reports or developer concerns, or any other relevant information. More generic environmental impacts specific to interconnectors should be provided for completeness, such as changes to the sea floor.	RAG
Landscape Impacts	Site specific impacts that are caused by the presence of interconnector infrastructure and how that may affect local historic assets and the landscape. Impacts due to site changes to accommodate IC infrastructure should be reported on as well as impacts during construction and maintenance.	The assumption is that a site and a design has been proposed, and drawings have been provided. Based on the site location, a drawing should be provided from the planning policy map. This can be accessed online via the relevant Local Authority website. The planning policy map will include historic and landscape designations and indicate potential historic and landscape impacts. Drawings for the site should indicate the scale of any buildings and demonstrate how the IC infrastructure will sit within the landscape. Photos or CAD drawings can also be provided. Any relevant information that may support a RAG rating should also be provided. This may include any initial site reports or developer concerns.	
Noise/ Disturbance	Site specific impacts that occur due to the IC infrastructure.	Noise during the operation of IC infrastructure, construction the associated traffic and maintenance is well understood due to the existence of other interconnector sites.	

Impact	Definition	Information the developer should provide	Assessment Approach
	Impacts due to site changes to accommodate IC infrastructure should be reported on as well as impacts during construction and maintenance.	The site location and proposals for routing construction traffic are likely to determine the scale of the noise impact. These should be provided alongside any other information that may be relevant.	
Impacts on Local Community	Site specific impacts that concern site changes to accommodate IC infrastructure and how this may impact the local community. This may include impacts on roads and transport, existing buildings, and services. Impacts due to site changes to accommodate IC infrastructure should be reported on as well as impacts during construction and maintenance.	The assumption is that a site and a design has been proposed, and drawings have been provided for these. Based on the site location, a copy of the location should be drawn from the planning policy map. This can be accessed online via the relevant Local Authority website. The planning policy map will include roads, churches, parks, and other sites that may be locally important. The developer should communicate whether the site has any existing uses that may be significant to the local community and whether this use is likely to change. Any other relevant information to support a RAG rating should also be provided. This may include initial site reports or developer concerns.	

Monetisation

Unmonetized for the indicators above.

Best party to run the analysis

The developer is best placed to provide the information to inform the RAG rating. The RAG rating will then be assigned by Ofgem. Ofgem may ask the developer to provide further information in order for them to come to decision. Collaboration between the developer and Ofgem is encouraged and advised.

3.7. Other impacts

This indicator captures impacts, either positive or negative, of a project that are not already captured by the indicators proposed above. This indicator encourages developers to submit additional information for the assessment of unforeseen impacts that are not already covered by the assessment framework. These can then be considered as part of the needs case assessment.

Best party to run the analysis

The developer is best placed to provide information for Ofgem to review.

3.8. Assessment of MPIs

Based on a review of Ofgem’s consultation paper for Workstream 4 of the interconnector policy review, and the relevant stakeholders’ responses and information submissions, it can be concluded that MPIs do not present idiosyncratic benefits that have not already been captured by the proposed framework. This is further corroborated by ENTSO-E's opinion that its CBA guidelines are applicable to MPIs, as well as by the latest position of CEER and ACER on the EC offshore energy strategy.[29]

Arup, however, recognises that MPIs are a new type of asset at a very early stage of development. As new projects, project designs and business models are developed, additional benefits that are not already captured by the indicators proposed in this document, or that are unique to a specific project, might be identified. These impacts can be considered under the 'Other impacts' category described above.

3.8.1. Additional considerations

MPIs combine cross-border electricity trade with other activities, for example connecting offshore RES to shore, in one single asset. This presents significant new challenges from a legal, regulatory, and commercial perspective, as current arrangements do not directly apply to this new type of asset.

Such uncertainty has significantly hindered the deployment of MPIs in Europe, with only one active project to date (the Kriegers Flak Combined Grid Solution). This means that the challenges and barriers to the deployment of MPIs are not fully understood today, with new ones being likely to emerge as projects are developed.

Exploratory work is currently ongoing both in the UK and the EU to provide clarity and direction on topics such as the market arrangements underpinning the dispatch of RES generation and interconnector capacity, regulatory frameworks governing revenue streams and their allocation, roles and responsibilities of the different parties to an MPI and the connecting SOs, to name a few.[30]

It is therefore challenging to establish clear and firm rules on how to run a CBA analysis for MPIs when the core commercial, market and regulatory arrangements underpinning these projects are still uncertain. The modelling required to calculate the impacts of an MPI will be dictated by how Ofgem and project developers intend to define these aspects. The MPI pilot scheme that was introduced in December 2021 and is to be launched in mid-2022 by Ofgem, is a helpful framework where the practical aspects of a project and their implications can be openly discussed and agreed upon.

There are however some key areas that should be considered carefully when assessing MPIs. These are discussed in the following paragraphs.

3.8.2. Modelling approach, assessment framework and scope of the SEW analysis

MPIs deliver additional cross-border interconnection capacity, and because of this, they should be assessed alongside the interconnector projects participating in the same application window. Arup recommends following the same modelling approach used to assess interconnectors to ensure that both assets are assessed in a consistent and fair way. This includes, but is not limited to, using the same scenarios, assumptions, sensitivities, time horizon, interconnector baseline and modelling tools indicated in Appendix F of this document.

Similarly, the assessment framework presented in this paper should be used to evaluate the impacts of both interconnector and MPI projects. This includes applying the same indicators, underlying methodologies, and suitable parties to run the analysis identified for the assessment of interconnectors.

Arup also recommends following the ENTSO-E implementation guidelines when considering the SEW impacts of a new MPI project. This would ensure a degree of consistency in the analysis of the NRAs involved in the assessment of the project. As ENTSO-E suggests, compared to interconnector projects, the

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[29] ACER CEER Reflection on EC offshore strategy

[30] Ofgem's consultation on changes intended to bring about greater coordination in the development of offshore energy networks.

ENTSO-E Position on Offshore Development Market and Regulatory Issues scope of the SEW analysis for an MPI (i.e. the costs and benefits to be assessed) will differ slightly depending on the characteristics of the MPI project assessed.

- **OFTO-led model.** The project is built on top of a pre-existing or planned radial connection (i.e. the OFTO) to provide only an interconnector function connecting, for example, an offshore wind farm (OWF) to an additional country.

  Under this option, only the cost of the interconnector part of the MPI (L2 in Figure 5 below) and the cost of the offshore substation connecting the interconnector to the radial connection (if applicable) should be included in the CBA.

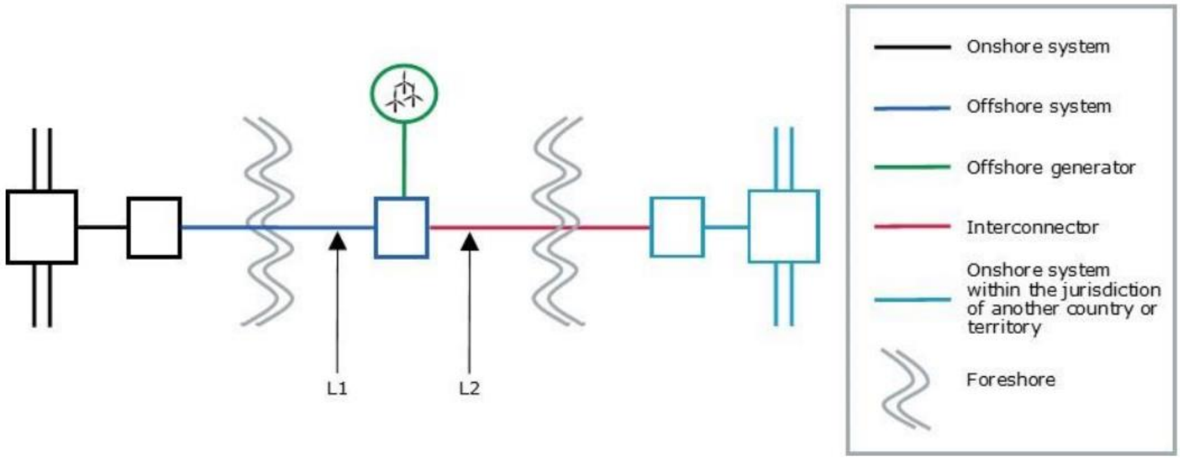

Figure 4 - OFTO led MPI model

Source: Ofgem

  All the impact indicators presented in this chapter are to be assessed, with the exception of the RES integration – 'Additional RES capacity' indicator. This is because under an OFTO-led model the OWF would not account for RES directly integrated by the project, as the OWF would have been developed even without the MPI.

- **IC-led model.** The project is developed as an MPI, enabling both the RES-integration function as well as the additional interconnector function.

  Under this option, the costs cover the entire length of the transmission cable (L1 in Figure 6 below) and includes the related substation to enable the RES infeed. The cost of the RES installation is excluded.

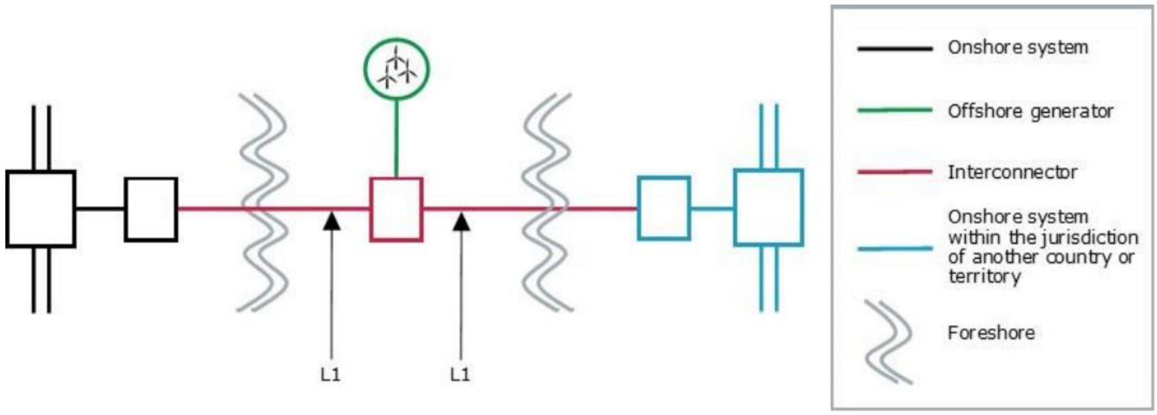

Figure 5 - IC led MPI model

Source: Ofgem

All impact indicators are to be assessed, including the RES integration – 'Additional RES capacity' indicator. This is because under this model the OWF would account for new RES directly integrated in the system by the MPI. In other words, the OFW would have not been built without the MPI project going ahead.

3.8.3. MPI specific modelling considerations

There are several aspects of MPIs that will require careful modelling, as they will significantly affect the calculation of the SEW impacts of a new project. Once again, it is difficult to suggest how to model the behaviour of an MPI project if key regulatory, commercial and market arrangements affecting that behaviour have not been clarified.

Once these are defined, in Arup's opinion, it should be possible to configure current modelling tools (e.g. PLEXOS, BID-3) to simulate the unique characteristics of an MPI project within the same market model used to assess traditional interconnectors. Therefore, it should be possible to develop a single model to assess both MPI and interconnector projects. This should be further explored by Ofgem and its consultant in the future.

Arup has identified the most relevant modelling considerations for MPIs in the following paragraphs.

Market arrangements

Both in the EU and the UK,[31] two sets of market arrangements that could govern MPI projects are currently under consideration. Depending on which one is selected, the generation assets connected to the MPI will be dispatched in different ways. This in turn will affect the flow of electricity on the cross-border transmission asset of the MPI.

- **The "home-market" (HM) setup**, whereby the OWF is considered, marketwise, part of the national onshore bidding zone (its HM). As such, the OWF will always bid and dispatch in its HM, receiving the clearing price of its HM. This is the current market setup in use for OWF.
- **The "offshore bidding zone" (OBZ) setup**, whereby the OWF has its own bidding zone and competes with market players of the onshore bidding zones it is connected to in order to access interconnector capacity. Hence, the price of the offshore bidding zone and the dispatch of the OWF depends on the neighbouring onshore bidding zones.

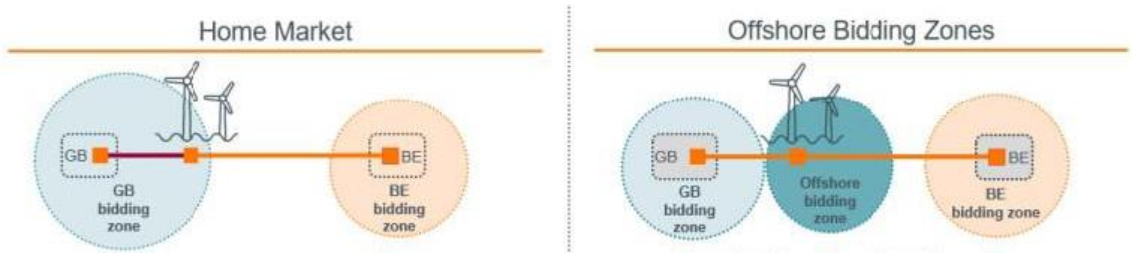

Figure 6 - Home market and offshore bidding zone market designs

Source: ENTSO-E

[31] Ofgem Interconnector policy review: Working paper for Workstream 4 - multiple purpose interconnectors
ENTSO-E Position on Offshore Development Market and Regulatory Issues
EC Communication COM(2020) 741

Allocation of producers SEW

Based on the above, the type of market arrangement selected will heavily influence the allocation of the producers welfare generated by the OWF between the two connected countries.

In Arup's opinion, under the HM set up, producer welfare should be allocated to the country in whose bidding zone the RES generation asset is located, as in this case the electricity generated will always be dispatched in the national bidding zone. Under the OBZ set up, the electricity generated will be dispatched towards either of the connected countries based on the prices of their national bidding zones, making difficult to allocate the correct potion of producer welfare associated with that OWF between the connected countries. Although the impact on the national and overall producer welfare may be minimal, especially for early MPI projects connecting a limited amount of offshore RES, Ofgem and its consultant should agree with their stakeholders the approach they intend to follow.

Calculation of the available capacity for trading

Depending on the MPI model, the capacity of the transmission asset(s) of an MPI will vary, and careful consideration should be given on how to model its availability, as this will directly affect the calculation of the SEW impacts. For instance, in an OFTO-led model (Figure 6 above), the volume of tradable electricity between two countries will be affected not only by the capacity of cross-border transmission asset (L2), but also by the capacity of the OFTO (L1) and the expected generation profile of the OWF. [32]

Commercial arrangements between the interconnector and OWF

Ofgem's consultant should consider how specific commercial arrangements between the parties of an MPI (e.g. charging arrangements and access tariffs) can influence the distribution of revenues among them.

Definition of the counterfactual

Developers should justify the preferred configuration of the project they will submit at the IPA stage, in line with the overall developer-led approach of the C&F regime. This means demonstrating that the proposed project is the most beneficial and feasible option among the alternatives considered.

Depending on the preferred configuration brought forward by developers, different combinations of alternatives should be considered. Indicatively, these could be:

- the same MPI model (i.e. OFTO-led or IC-led) with a different market set up from the one selected (i.e. HM or OBZ);
- a different MPI model with the same market set up;
- a different MPI model with a different market set up;
- a traditional point-to-point interconnector and/or a radial connection instead of an MPI.

The assessment that Ofgem will carry out at the IPA stage would measure the SEW impacts with the MPI project as proposed by developers (target case) and without the MPI (counterfactual). Depending on the model of MPI considered, the counterfactual will differ:

- for an IC-led MPI, the counterfactual would be the absence of the MPI project, including the generation assets it would connect, assuming that under this model the generation assets could not be developed without the MPI.
- For an OFTO-led MPI, the counterfactual would be represented by only the radial connection and the relevant offshore generation, assuming that these could be developed anyway even if the MPI is

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[32] Market arrangements could also influence the capacity of the cross-border transmission asset that can be used to dispatch the OWF when interacting with Article 16 of Regulation (EU) 2019/943 (recast). For additional information, please see Section 5 of ACER and CEER reflection on the EU strategy to harness the potential of offshore renewable energy for a climate neutral future.

not built.

3.8.4. Role of Ofgem

Ofgem should provide clarity on how the C&F regime will apply to the projects, specifying, at a minimum, the following:

- The elements of the MPI projects that will be included in the regulated asset base (RAB). This will depend on the MPI model considered, as described in the previous sections.
- The revenue streams that will be considered against the C&F levels.
- The areas of uncertainty that still exist and need to be considered further.

Ofgem should also proactively engage with the relevant NRAs to understand key regulatory and legal challenges presented by the projects considered and identify potential solutions.

3.8.5. Role of the developers

Developers should provide clarity on the key aspects underpinning the business model of their project, specifying the following:

- The preferred MPI model they intend to develop. This will help determining the composition of the RAB and the scope of the assessment.
- The preferred market arrangement governing the project (i.e. HM or OBZ). This will help determine how the RES generation connected to the MPI will be dispatched, which in turn will influence the cross-border interconnector capacity and therefore the level of congestion revenues the project can earn.
- Any agreement that the TO, OFTO and offshore RES generator might sign to determine roles, responsibilities and commercial relations between the parties participating in the MPI, if any. This will help understanding the risk and reward balance attributable to each party of the MPI.
- Technical details of and information (e.g. location, development timelines, technology, etc.) of the offshore RES generation asset, as well as of the transmission assets of the MPI.

Developers should also provide technical details and information on the offshore RES generation asset and the transmission assets making up the MPI. This should include, but may not be limited to, the justification of technical design, cables route, location of onshore connection points and RES generation assets, technology choices, technical specifications of generation and transmission assets such as capacity, voltage, loss factors and load factors. Arup notes that the level of detail of this information may be affected by the relative early development stage of MPI projects applying to Window 3. This should be taken into account by Ofgem when assessing these projects.

3.9. Summary of recommendations

Arup recommends utilising a total of 22 standalone indicators describing the impacts of new interconnector and MPI projects under seven impact categories, as described above.

The indicators describing SEW impacts, decarbonisation and security of supply are calculated through an economic market modelling tool. In Arup's opinion, the most appropriate party for running this analysis are the consultant on behalf of Ofgem, given the specific expertise and modelling capabilities they can provide. To assess a project's impact under these categories, the only information required from developers are the expected project costs, which are used to determine net SEW figures and expected C&F payments for the assessed project.

Arup suggests making the submission of the SEW analysis from developers as optional, rather than a mandatory requirement as in previous application windows. Developers should, however, retain the option to submit their analysis if they wish to do so. The analysis should follow the methodology used by Ofgem to determine the values of the relevant indicators to ensure consistency in the results. If developers wish to apply any change, these should be fully justified. Whilst the developers' analysis should not determine the outcome of the IPA decision, it could inform Ofgem's own modelling and analysis.

Network costs should be calculated by the relevant TO during the CION process and be provided by the developers themselves when submitting their C&F application to Ofgem. Developers are best placed to provide information regarding expected hard-to-monetise impacts.

For the calculations of the system operability and flexibility indicators, Arup has identified the ESO as the most appropriate party to run the analysis. The ESO holds the necessary data, technical expertise, modelling tools and deep knowledge of the electricity system required to run such an analysis. To improve NGESO's analysis of the system operability indicators, developers can provide information regarding the ability of the project to meet Grid Code ECC.6.3.19 GRID FORMING CAPABILITY, if applicable.[33] No additional information is required from developers for the analysis of the flexibility indicator. A comparison between the information required from developers at Window 2 and in future windows is presented in Appendix G.

Importantly, the same indicators can be used to assess MPI projects, as they already capture the potential impacts of this new type of asset. The actual modelling of the impacts, however, will differ from that required to assess interconnector projects. Collaboration between Ofgem and project developers will be necessary to agree key regulatory and commercial aspects of the project assessed, which in turn will dictate the modelling of its impacts.

[33] GC0137: Minimum Specification Required for Provision of GB Grid Forming (GBGF) Capability (formerly Virtual Synchronous Machine/VSM Capability). This modification seeks to implement a minimum specification for generators wishing to offer VSM capability – in that the affected plant responds more like traditional plant. Such plant would react to unplanned events/faults in a manner which does not result in a severe drop in frequency, allowing for balancing and response services to correct the drop in frequency in a more timely and predictable manner.

4. Options for a new assessment framework

Chapter summary:

This chapter presents the overarching assessment framework designed to support Ofgem in reaching a final decision at the IPA stage. Arup proposes to use a multicriteria assessment framework that combines both qualitative and quantitative indicators and that can help Ofgem understanding the trade-offs of the different projects assessed. Arup recommends not to use a weighted scoring system as this would automatically determine the outcome of assessment, limiting Ofgem's role of final decision maker at the IPA stage.

The chapter also includes a working example of how three hypothetical projects would be assessed under the new framework.

4.1. Overview of the proposed framework

Based on Ofgem's requirements, the new assessment framework must enable effective and transparent decision making on whether specific projects are in the interest of consumers and should therefore be awarded a C&F regime in principle.

In Arup's view, this means that the framework needs to support Ofgem in identifying the positive and negative impacts of each project, allowing for their direct comparison under the different indicators proposed, in order to select the projects that best serve consumers' interest. Equally, the framework should help provide clarity to stakeholders on how Ofgem reached a final decision at the IPA stage.

The framework will allow developers to demonstrate how their projects meet GB consumers' interests beyond the traditional assessment of SEW. This is of critical importance for future needs case assessments. Additional interconnection capacity coupled with increasing RES deployment in both the UK and its neighbouring countries will likely reduce price differentials, which have historically favoured GB consumers. As the potential SEW benefits to the consumer might decrease compared to the past, it is fundamental for Ofgem to understand where new projects in other areas can benefit British consumers to make an informed decision.

As indicated in the previous chapter, Arup proposes the adoption of a multicriteria assessment framework that includes a wide range of both quantitative and qualitative impact indicators, in recognition of the fact that not all impacts can be captured by a single monetary value. It is important to note that in this type of framework there will always be a certain degree of discretion that cannot be fully removed. A potential option to mitigate this would be defining the weight each decision criterion. However, this would inherently create a deterministic, rigid assessment framework that would lock Ofgem's decision into a result that is derived arithmetically.

Therefore, in alignment with the Green Book appraisal principles, Arup has designed a framework that supports the Ofgem decision making process, rather than one that replaces Ofgem in reaching a decision. The framework proposed provides an extensive set of information that Ofgem can use to reach a final decision at the IPA stage in a transparent way based on how each and every project best serves GB consumers' interest.

4.2. A multicriteria assessment framework

As discussed in this document, the new multicriteria assessment framework is based on seven impact categories, namely: (i) SEW; (ii) network costs; (iii) system operability, (iv) flexibility, (v) decarbonisation, (vi) security of supply, and (vii) hard-to-monetise impacts.

Each impact category is composed of different indicators, described in Table 8 below. The majority of the indicators are either monetised or quantified, with only the hard-to-monetise impacts being assessed qualitatively. Ofgem's decision will therefore be informed by a project's performance under of each of these indicators.

Table 8 - List of the Proposed Impact Categories, Indicators and Units

Impact category	Indicator	Unit
SEW	Consumers SEW	£m/y
	Producers SEW	£m/y
	Interconnectors SEW	£m/y
	Total SEW	£m/y
Network costs	Onshore works	£m/y
System operability	Frequency stability	MW/h
	Frequency response savings	£m/ MW/h
	Voltage stability	MVar
	Reactive response savings	£m/MVar
	Black start	£m/y
Flexibility	Balancing Market impacts	£m/y
Decarbonisation	CO_2 reduction (SEW)	£m/y
	CO_2 reduction (Societal value)	£m/y
	RES integration (avoided RES spillage)	MWh/y
	RES integration (additional RES capacity)	MW
	Overall decarbonisation	t
Security of Supply	Cost of EENS	£m/y
Hard-to-monetise impacts	Environmental impact	qualitative
	Local community impacts	qualitative
	Noise/Disturbance	qualitative
	Landscape	qualitative
	Other impacts	qual/quant

To reach a final decision using this framework, four key steps are required. These are:

1. **Data collection:** All projects considered eligible and mature enough by Ofgem are assessed together. The value for each indicator is derived for all projects and inputted in a table as displayed above.
2. **Colour coding:** A colour system is used to determine positive, marginal and negative impacts under each indicator of each project assessed. This is the first step of the preference building process leading to a final decision, based on a first high-level identification of the strengths and weaknesses of each project.

   If required, a selection of indicators can be used to sift projects. These can be used to test whether a project satisfies strategic priorities for Ofgem, before moving to a more detailed assessment. We note that for Window 3, it is unlikely to use this step for sifting due to the maturity level of the framework.
3. **Performance comparison:** Projects are ranked against each other (simple relative scoring) to identify the best performing project under each indicator. The scores are summed together to provide an overview of the best performing project under each impact category. This is the second step of the preference building process leading to a final decision.

   This step can also be used to shortlist the best performing projects, in circumstances where there may be a limit to the number of interconnectors that can be awarded a C&F regime in any given application window.
4. **Verification:** The results of Step 3 are cross-checked with the actual performance of each project under each indicator to re-examine in more detail the relevance of each indicator's result, and determine which project satisfies consumers' interests. This is the final step of the preference building process.

It is important to note that the final decision is not based on the outcome of a single step. Rather, it is based on the combination of the outcomes of each step taken together.

4.2.1. Step by step description of the framework

The following paragraphs describe in detail each step of the assessment process, using three notional projects as an example. It is worth noting that the figures presented are only indicative and do not represent any real project. They are based on high-level project profiles developed for explanatory purposes.

Arup assumed that there is a limit to the number of projects that can obtain a C&F regime. Once again, this has been done exclusively for explanatory purposes to showcase how the framework could be used in such circumstances, if required. This does not reflect any decision on this matter by Ofgem. If Ofgem intends to use any of the features of the framework, Arup recommends that this is communicated well in advance to its stakeholders.

Step 1: Data collection

Under Step 1, the values for each indicator are derived and presented in table format, as shown below. The aim of this step is simply to provide an overview of the results of the assessment run at the IPA stage.

Table 9 - Example of Step 1 – Data Collection

Impact category	Indicator	Unit	Project A	Project B	Project C
SEW	Consumers SEW	£m/y	-30	50	150
	Producers SEW	£m/y	50	-35	-190
	Interconnectors SEW	£m/y	-5	-10	-30
	Total SEW	£m/y	15	5	-70
Network costs	Onshore works	£m/y	-5	-15	-10
System operability	Frequency stability	MW/h	30	10	80
	Frequency response savings	£m/ MW/h	80	30	150
	Voltage stability	MVar	20	30	70
	Reactive response savings	£m/MVar	70	80	120
	Black start	£m/y	50	n/a	60
Flexibility	Balancing Market impacts	£m/y	50	-10	100
Decarbonisation	CO_2 reduction (SEW)	£m/y	200	-20	10
	CO_2 reduction (Societal value)	£m/y	300	-120	60
	RES integration (avoided RES spillage)	MWh/y	200	-50	10
	RES integration (additional RES capacity)	MW	0	0	0
	Overall decarbonisation	t	30	5	-20
Security of Supply	Cost of EENS	£m/y	100	-100	150
Hard-to-monetise impacts	Environmental impact	qualitative	+	-	--
	Local community impacts	qualitative	-	+	-
	Noise/Disturbance	qualitative	--	+	+
	Landscape	qualitative	+	--	-
	Other impacts	qual/quant	n/a	n/a	n/a

In this example, positive values indicate beneficial impacts delivered by each project (e.g. cost savings, gains to society, reduction of carbon emissions, etc.), while negative values indicate detrimental impacts (e.g. increased costs, losses to society, increase in carbon emissions, etc.). This also applies to frequency and voltage stability impacts.

The indicators as presented above (and throughout the proposed assessment framework) consist in point values generated under a central scenario using the MA approach [34] (or a similar approach), as in the past

[34] This does not apply to the Hard-to-monetise impacts.

Ofgem’s decision making was based on the results of the MA run. Whilst this improves overall readability, it does not allow for an assessment under the different scenarios used in the analysis. See Section 4.2.3 for robustness against scenarios.

Step 2: Colour coding

Under this step, a RAG colour system is used to identify negative, marginal, and positive impacts for each project, based on the indicator values summarised in Step 1. The aim of this step is to quickly identify the best and least performing projects overall. This is the first step of the preference-building process leading to a final decision.

Table 10 - Example of Step 2 – Colour Coding

Impact category	Indicator	Unit	Project A	Project B	Project C
SEW	Consumers SEW	£m/y			
	Producers SEW	£m/y			
	Interconnectors SEW	£m/y			
	Total SEW	£m/y			
Network costs	Onshore works	£m/y			
System operability	Frequency stability *	MW/h			
	Frequency response savings	£m/ MW/h			
	Voltage stability *	MVar			
	Reactive response savings	£m/MVar			
	Black start	£m/y			
Flexibility	Balancing Market impacts	£m/y			
Decarbonisation	CO_2 reduction (SEW) **	£m/y			
	CO_2 reduction (Societal value) **	£m/y			
	RES integration (avoided RES spillage)	MWh/y			
	RES integration (additional RES capacity)	MW			
	Overall decarbonisation	t			
Security of Supply	Cost of EENS	£m/y			
Hard-to-monetise impacts	Environmental impact	qualitative			
	Local community impacts	qualitative			
	Noise/Disturbance	qualitative			
	Landscape	qualitative			
	Other impacts	quant/qual			

* These indicators should be considered together with their monetised version to avoid double counting in the assessment process
** These indicators should be considered together to avoid double counting in the assessment process

The amber category of the RAG colour system indicates marginal impacts under the relevant indicator, either positive or negative. Ofgem should determine the scales underpinning this classification in agreement with key stakeholders during the modelling workshop.

If required, Step 2 also allows Ofgem to sift projects based on their performance under key impact indicators (or impact categories), in line with the Green Book’s recommendation to create decision points to streamline the assessment process and facilitate the decision maker.

The key indicators (or categories) selected would reflect what Ofgem considers to be a strategic priority for GB consumers. Ofgem will have to indicate what these strategic priorities are when announcing a new application window. We note that Ofgem does not intend to use this feature for Window 3.

This feature can be particularly helpful if there is a limit to the number of projects that can be granted a C&F regime in a given application window. For example, projects delivering negative impacts under the selected indicators (or categories) could be removed from the assessment. Alternatively, if at the end of the assessment process (i.e. Step 4), two or more projects present very similar potential impacts, Ofgem could look at how many indicators (or categories) each project is expected to deliver positive impacts when reaching an IPA decision.

Step 3: Performance comparison

Under this step, a scoring system is overlaid onto the results of Step 2. The aim of this step is to identify the best performing projects under every indicator. Additional rows are added to identify the projects' performance for every impact category too. This is the second step of the preference building process leading to a final decision.

Table 11 - Example of Step 3 – Performance Comparison

Impact category	Indicator	Unit	Project A	Project B	Project C
SEW	Consumers SEW	£m/y	3	2	1
	Producers SEW	£m/y	1	2	3
	Interconnectors SEW	£m/y	1	2	3
	Total SEW	£m/y	1	2	3
Network Costs	Onshore works	£m/y	1	3	2
System Operability	Frequency stability *	MW/h	2	3	1
	Frequency response savings	£m/ MW/h			
	Voltage stability *	MVar	3	2	1
	Reactive response savings	£m/MVar			
	Black start	£m/y	2	3	1
	Total score		**7**	**8**	**3**
Flexibility	Balancing Market impacts	£m/y	2	3	1
Decarbonisation	CO_2 reduction (SEW) **	£m/y	1	3	2
	CO_2 reduction (Societal value) **	£m/y			
	RES integration (avoided RES spillage)	MWh/y	1	3	2
	RES integration (additional RES capacity)	MW	0	0	0
	Overall decarbonisation	t	1	2	3
	Total score		**3**	**8**	**7**
Security of Supply	Cost of EENS	£m/y	2	3	1
Hard-to-Monetise Impacts	Environmental impact	qualitative	1	2	3
	Local community impacts	qualitative	2	1	2
	Noise/Disturbance	qualitative	2	1	1
	Landscape	qualitative	1	3	2
	Other impacts	quant/qual	0	0	0
	Total score		**6**	**7**	**8**

* These indicators should be considered together with their monetised version to avoid double counting in the assessment process
** These indicators should be considered together to avoid double counting in the assessment process

The scoring method suggested is a relative scoring, whereby projects are assessed against each other. The range of the scoring is based on how many projects are assessed (in this case, 1 to 3). The best performing project obtains a score of 1, the next best performing project obtains a score of 2, and so on.

For those impact categories composed of multiple indicators, the score for each indicator is then summed together to provide an overview of how a project is expected to perform under that impact category. It is worth noting that this is not required for the SEW results, as they are already expressed in terms of total SEW as well as broken down by stakeholder group. Evaluating a project based on the SEW score sum could be misleading, as Arup thinks it is important to understand both the impacts a new project can have on society overall as well as those on each stakeholders' group.

It is important to note that this step in itself does not form the basis for the final decision. It can be noticed that the scores are not summed together to derive a single, total score for each project on which to base a decision. As mentioned earlier in this document, the framework is designed to support Ofgem in reaching a final decision and not to replace Ofgem by arithmetically determining the outcome of the assessment. Consequently, it is not necessary to determine the weight each category has in the final score. This step aims at providing Ofgem with a detailed overview of which project better meets consumers' interests compared to the others. Like Step 2, this information can be particularly useful when there are limits on the number of interconnectors that can be selected in a given window.

Step 4: Verification

Under this step, the scores given in Step 3 are cross-referenced with the actual indicator values. The aim of this step is to assess the variation of the values of each indicator to determine the actual impact each project can have under each category.

As mentioned earlier, Step 3 in itself does not constitute the basis for a final decision. The scoring of the projects' performance might be determined by marginal differences as well as substantial variations in each category. Therefore, it is important for Ofgem to understand the trade-offs of each project to build an informed opinion before reaching a final decision.

For example, a project could deliver marginally better impacts under most indicators compared to other projects, but it could deliver significantly negative total SEW benefits. Based on Step 3, the project would score better overall, suggesting it would be an excellent candidate for the C&F regime. However, Ofgem would need to also consider the magnitude of the negative impacts on SEW before taking a final decision.

The following paragraphs provide a working example of how the framework can be used to gather information about the three notional projects to reach a final decision.

Table 12 – Example of the Complete Assessment Framework

Impact category	Indicator	Unit	Project A		Project B		Project C	
SEW	Consumers SEW	£m/y	3	-30	2	50	1	150
	Producers SEW	£m/y	1	50	2	-35	3	-190
	Interconnectors SEW	£m/y	1	-5	2	-10	3	-30
	Total SEW	£m/y	1	15	2	5	3	-70
Network Costs	Onshore works	£m/y	1	-5	3	-15	2	-10
System Operability	Frequency stability *	MW/h	2	30	3	10	1	80
	Frequency response savings	£m/ MW/h		80		30		150
	Voltage stability *	MVar	3	20	2	30	1	70
	Reactive response savings	£m/MVar		70		80		120
	Black start	£m/y	2	50	3	n/a	1	90
	Total score		**7**		**8**		**3**	
Flexibility	Balancing Market impacts	£m/y	2	50	3	-10	1	100
Decarbonisation	CO_2 reduction (SEW) **	£m/y	1	200	3	-20	2	10
	CO_2 reduction (Societal value)**	£m/y		300		-120		60
	RES integration (avoided RES spillage)	MWh/y	1	200	3	-50	2	10
	RES integration (additional RES capacity)	MW	0	0	0	0	0	0
	Overall decarbonisation	t	1	30	2	5	3	-20
	Total score		**3**		**8**		**7**	
Security of Supply	Cost of EENS	£m/y	2	100	3	-100	1	150
Hard-to-Monetise Impacts	Environmental impact	qualitative	1	+	2	-	3	--
	Local community impacts	qualitative	2	-	1	+	2	-
	Noise/Disturbance	qualitative	2	--	1	+	1	+
	Landscape	qualitative	1	+	3	--	2	-
	Other impacts	quant/qual	0	n/a	0	n/a	0	n/a
	Total score		**6**		**7**		**8**	

* These indicators should be considered together with their monetised version to avoid double counting in the assessment process
** These indicators should be considered together to avoid double counting in the assessment process

Table 12 brings together all four steps of the framework, providing the complete overview of the overall, relative, and actual performance of three notional projects applying to a given C&F window.

At first sight, Project A performs well across the board, delivering negative impacts under fewer indicators compared to the other two projects. It is also the best performing project in terms of decarbonisation and hard-to-monetise impacts. However, it would be the only project delivering negative consumer SEW impacts.

Project B is expected to deliver positive total and consumer SEW impacts. Nonetheless, project B underperforms consistently compared to the other projects overall, except for the hard-to-monetise impact category.

Project C is the lowest performing project in terms of total SEW impacts, however it is expected to deliver the highest consumer SEW. The project also scores well under the system operability and security of supply impact categories; however, it would be the most disruptive project under the hard-to-monetise impact category.

The framework allows Ofgem to dig deeper in this initial analysis. While Project B can be identified as the lowest performing project of all those considered, the other two projects present different trade-offs. For example, Project C could deliver materially higher consumer SEW compared to Project A. This however would be counterbalanced by substantial negative SEW impacts for producers. Project C could also deliver almost twice as much in system cost savings when providing Ancillary Services compared to Project A, and much higher constraint cost savings. Project A largely outperforms Project C under all the decarbonisation indicators, with the latter increasing the overall net emission in the connected countries. Finally, Project C is also expected to deliver higher benefits for the security of supply compared to Project A.

Each project has its own strengths and weaknesses. All these factors must be carefully considered going forward, as the underlying economics of interconnector projects have changed. For example, under the previous assessment framework, it would have been hard to justify awarding a C&F regime to Project A, showcasing negative consumer SEW impacts. However, it could have meant rejecting a project that could have greatly contributed to the UK's climate objectives. The new framework will allow Ofgem to consider a number of benefits that projects could deliver, basing its IPA decision to a much more detailed and nuanced range of information compared to previous assessments.

4.2.2. Examples of the implementation of the assessment framework

As mentioned above, this framework presents features that would allow Ofgem to compare and identify the projects that reflect what Ofgem considers better represents consumers' interests based on key criteria. The example below illustrates how these features can be implemented using the same three notional projects considered above.

Example 1 – Key criterion

Under this example, it is assumed that Ofgem has primary criterion is decarbonisation, as key criterion to help select which projects should be awarded a C&F in principle.

In this case, Project A and Project C would overall perform better than Project B, which would not only increase CO_2 emissions, negatively affecting the overall SEW by £20m/y, but it would also increase RES curtailment by 50MWh/y.

Project C would deliver more positively although with marginal impacts, reducing CO_2 emission (SEW) and related costs by £10m/year, CO_2 emission (Societal value) by £60m/year, and RES curtailment by 10MWh/y. However, the project is expected to increase the overall carbon emissions by 20tCO_2 each year, for example because it connects to a country whose energy mix heavily relies on cheap fossil fuel generation.

Table 13 - Focus on Decarbonisation as Key Criterion

Impact category	Indicator	Unit	Project A		Project B		Project C	
SEW	Consumers SEW	£m/y	3	-30	2	50	1	150
	Producers SEW	£m/y	1	50	2	-35	3	-190
	Interconnectors SEW	£m/y	1	-5	2	-10	3	-30
	Total SEW	£m/y	1	15	2	5	3	-70
Decarb.	CO2 reduction (SEW)	£m/y	1	200	3	-20	2	10
	CO_2 reduction (Societal value)	£m/y		300		-120		60
	RES integration (avoided RES spillage)	MWh/y	1	200	3	-50	2	10
	RES integration (additional RES capacity)	MW	0	0	0	0	0	0
	Overall decarbonisation	t	1	30	2	5	3	-20
	Total score		3		8		7	

Project A would therefore be the best performing project of the three considered. It would provide substantial CO_2 cost reductions of £200m/y, relieve a congested area with high RES generation reducing curtailment by 200MWh/y, and reduce overall net CO_2 emissions in the connected countries by 30tCO_2 per year. Therefore, in this example, Project A would be the most preferable project, followed by Project C and with Project B being the least preferable project.

However, this should not be the only element forming the basis of a final decision. In fact, Ofgem would need to assess the various trade-offs between the projects. Project A is the best performing under the decarbonisation category. However it is expected to deliver negative consumer SEW impacts. On the other hand, Project B and C would increase consumer SEW by £50m/y and 150m/y respectively. Finally, only Project A and B are expected to deliver positive total SEW impacts (£15m/y and £5m/y, respectively) compared to Project C (negative £70m/y).

Ofgem might consider that the decarbonisation benefits of Project A are material enough to award a C&F regime to a project delivering relatively negative consumer SEW impacts, but overall positive total SEW impacts. In this specific case, considering that the value of the indicator 'CO_2 reduction (SEW)' is extrapolated from the overall SEW calculations, Ofgem should interrogate the drivers and relation behind extremely high CO_2 reduction benefits, marginal total SEW impacts and yet negative consumer SEW impacts, drilling into the modelling. This would help breaking down further the case of a specific project, stress testing the rationale behind the value of the indicators assessed to inform the final decision. This verification step is integral to the assessment framework proposed and should always be implemented.

Similarly, Project C might not perform well in terms of overall CO_2 emission reduction. However, this is potentially offset by the substantial expected consumer benefits. On the contrary, Project B's SEW performance might not be enough to compensate for the substantia negative decarbonisation impacts if that is deemed the key primary criterion.

Example 2 – Minimum requirements

Alternatively, Ofgem can select a set key impact categories as minimum requirements that project needs to meet to be awarded a C&F regime in principle. In other words, Ofgem would select the projects delivering the highest SEW benefits, if they meet the indicated minimum requirements.

For example, projects could be required to deliver either marginal or positive impacts under the flexibility, decarbonisation and security of supply impact categories. In this case, Project B and Project C provide positive consumers SEW impacts. However, only project C delivers consumers SEW benefits and meets the minimum requirements indicated. In fact, Project C is expected to deliver significant benefits in flexibility (£100m/y) and security of supply (reducing EENS costs substantially, and only marginal decarbonisation impacts. On the contrary, Project B is expected to deliver significant negative impacts on all the categories selected as minimum requirements. Under this illustration, only Project C would receive a C&F.

Table 14 - Focus on Minimum Requirements

These examples are also applicable when there is a limit to the number of projects that can be selected for a C&F regime in a given application window. For instance, a limit to the interconnector capacity available in a given application window could mean that only two projects out of three applying can be granted a C&F in principle. In such scenario, Ofgem could use the features described above to shortlist the projects assessed, streamlining its decision-making process. Table 15elow shows potential outcomes of doing so.

Impact category	Indicator	Unit	Project A		Project B		Project C	
SEW	Consumers SEW	£m/y	3	-30	2	50	1	150
	Producers SEW	£m/y	1	50	2	-35	3	-190
	Interconnectors SEW	£m/y	1	-5	2	-10	3	-30
	Total SEW	£m/y	1	15	2	5	3	-70
Flexibility	Balancing Market impacts	£m/y	2	50	3	-10	1	100
Decarb.	CO_2 reduction (SEW)	£m/y	1	200	3	-20	2	10
	CO_2 reduction (Societal value)	£m/y		300		-120		60
	RES integration (avoided RES spillage)	MWh/y	1	200	3	-50	2	10
	RES integration (additional RES capacity)	MW	0	0	0	0	0	0
	Overall decarbonisation	t	1	30	2	5	3	-20
	Total score		**3**		**8**		**7**	
Security of Supply	Cost of EENS	£m/y	2	100	3	-100	1	150

Under Example 1, shortlisting projects by the decarbonisation impact category would lead to the selection of Projects A and C, with Project B being discarded from the assessment.[35] Under Example 2, only Project C is shortlisted as it the only project delivering positive consumer SEW impacts and meeting the minimum requirements. This would leave spare interconnector capacity yet to be allocated in the application window. In this case, Ofgem could use the framework to identify the second-best project to be selected from the projects that were not short listed (the 'reserve' in Table 15 below).

In this specific example, it is assumed that priority is given to those projects meeting the minimum requirements, hence, to Project C given that marginally negative consumers SEW are offset by overall positive impacts (including total SEW).

Table 15 - Example of Projects' Selection

Examples	Selected category	Shortlisted	Reserve	Discarded
Example 1 **Key criterion**	Decarbonisation	Projects A and C	None at this stage (for this example) as the window capacity cap is met by Projects A and C.	Project B
Example 2 **Minimum requirements**	Flexibility Decarbonisation Security of supply	Project C is shortlisted as it is the only project delivering positive or marginal impacts under all categories.	There is still room for a second project in this application window. Project A can be put in reserve as second-best project it does not maximise SEW, but it meets all minimum requirements. Ofgem would then need consider the various trade-offs of this project.	Project B

How to prioritise impact categories underpinning the selection process

As suggested in this chapter, Ofgem might be required to indicate which impact categories it considers better represent the interests of GB consumers, in order to support its decision-making process. In section 4.1, Arup recommends avoiding the use of weights, as this would inherently create a deterministic, rigid assessment framework that would derive a final result arithmetically. This would also potentially require Ofgem to consult on and agree with its key stakeholders the proposed weights, which might be challenging and subjective depending on the person making the decision.

In Arup's opinion, the key impact categories to consider could be selected based a range of relevant sources which could be include, but may not be limited to:

- Ofgem's statutory duties;
- Ofgem's Forward Work Programme, setting out its strategy for regulating the energy landscape and protecting consumers;
- UK Government's energy and climate policy objectives, defined in its White Papers or other relevant documents at the time of the Window; and
- NGESO's Operability Strategy Report, addressing the operational challenges the ESO faces and defining the operational requirements and future system needs;

[35] It is worth noting that this should not preclude Project B to apply to the next application windows.

If, however, in the future Ofgem prefers using weights to support its decision-making process, Arup recommends referring to the Green Book's supplementary guidance on multi-criteria decision analysis to ensure adherence to the Government's best practices and principles.[36]

4.2.3. Robustness against scenarios

We recommend testing the robustness of the decision against different scenarios. Whilst Arup recommends Ofgem to base its needs case assessment on FES scenarios, not all four of them need to be modelled. The relevant scenarios to be used by all relevant parties (i.e. Ofgem's consultant and NGESO) will be selected in the modelling workshop with key stakeholders. As a suggestion, the scenarios with the highest, median and lowest volume of power flowing through interconnectors could be selected [37] as High-case, Base-case and Low-Case Scenarios for interconnector economic value, respectively.

As a minimum, the SEW results should be analysed for all selected scenarios. Ideally, all indicators should be analysed for all selected scenarios, except for the hard-to-monetise impacts.

If a project performs uniformly across scenarios, this will indicate that the consumer and system benefits are robust and would not require further consideration. If the results and scoring show significant variation across scenarios (especially if some impacts flip from costs to benefits and vice versa), then we recommend Ofgem consider the most likely scenario to support a decision. If a project provides significant consumer disbenefit under a key scenario, we recommend this risk be further assessed by Ofgem.

If the scenarios provide materially different values for each project, then the base case could be used as the ultimate reference scenario. Alternatively, the FES scenario where the lowest volume of power flows through interconnector could be used as the reference scenario as it represents the most conservative choice whereby the economic value of interconnectors is minimised due to a lower price differential.

4.3. Other options considered

Arup considered two other options for the needs case assessment framework which were, however, at least in part, discarded. These are an unmodified multi-criteria decision analysis (MCDA) framework and the Green Book's longlist-short list framework.

MCDA framework

The MCDA is a decision-making tool that considers multidimensional factors and enables comparison of different solutions to a problem by combining individual criteria into one overall appraisal. It is most applicable to solving problems that are characterized as a choice among alternatives, where one or more decision makers define the problem to be solved in alignment with their preferences and priorities.

Once a goal is set, a list of evaluation criteria is then developed, against which the alternatives considered are assessed and rated. Criteria would then be weighted based on the importance given by decision makers to each of them. A weighted final score is then obtained for each of the alternatives considered, which will then be ranked and selected accordingly.

[36] Green Book supplementary guidance: multi-criteria decision analysis

[37] Data available in the FES Databook – Tab ES1

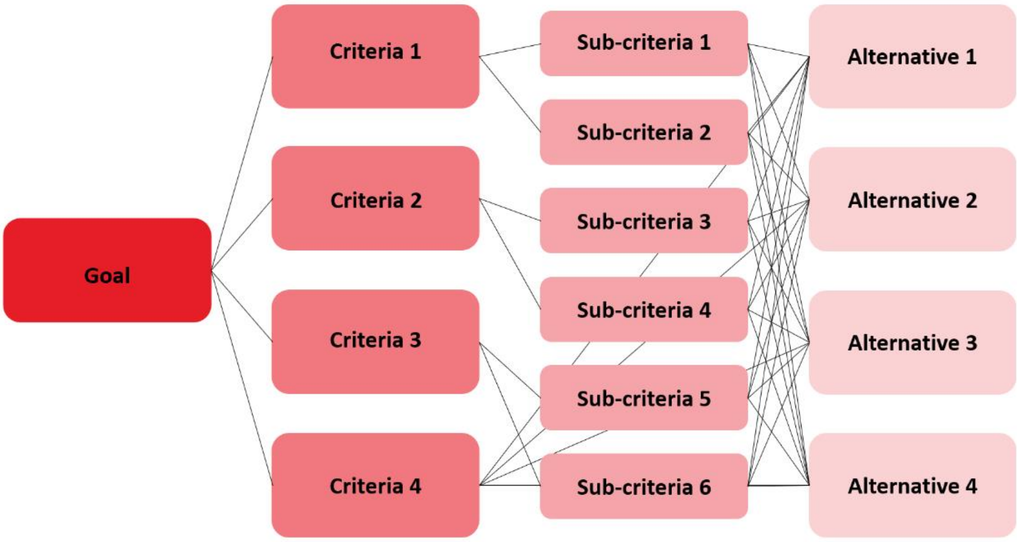

Figure 8 – Example of a Multi-Criteria Decision Analysis (MCDA) Framework

While this framework underpins the proposed needs case assessment framework, Arup's proposal does not include weighting nor a final score for the projects (i.e. alternatives) considered in each window, for two main reasons.

Firstly, using weightings and final scores would lead to a decision determined arithmetically. Ofgem's role as decision maker would have been removed as the framework would automatically derive an answer. As per Green Book's guidance, Arup preferred instead developing a tool that would support Ofgem in reaching a decision.

Secondly, considering that each impact category is composed of several indicators, each indicator would have required to be weighted individually as well as the impact categories as a whole. This would have made the framework overly complex and open to challenge.

Longlist-shortlist framework

This appraisal method is described in the Green Book. Under this framework, a final decision is reached by sifting potential options through different selection stages, using a list of assessment criteria. Longlist analysis helps understand which option can best achieve a certain objective based on the wider lens of public service provision to avoid bias towards certain solutions. Only those options meeting the relevant criteria are then shortlisted for a further detailed assessment of the associated cost, benefits and trade-offs.

As already covered in Chapter 2, this framework does not strictly apply to the type of assessment that Ofgem is required to undertake when assessing new interconnector or MPI projects. In fact, the vast majority of the indicators proposed in this document are derived through the detailed analysis of the SEW impacts.

Nonetheless, this framework creates multiple decision points that simplify and streamline the decision-making process if required. As covered in Chapter 3, Arup decided to include this feature in the proposed framework as an option for Ofgem to use if required. In such circumstances, Ofgem should notify its stakeholders when opening a new application window

Appendix A - BID3 power market model

BID3 is Pöyry's power market model, used to model the dispatch of all generation on the European network. It simulates all 8,760 hours per year, with multiple historical weather patterns, generating hourly wholesale prices for each country for each future year and dispatch patterns and revenues for each plant in Europe.

Modelling Methodology

BID3 is an economic dispatch model based around optimisation. The model balances demand and supply on an hourly basis by minimising the variable cost of electricity generation. The result of this optimisation is an hourly dispatch schedule for all power plants and interconnectors on the system. At the high level, this is equivalent to modelling the market by the intersection between a supply curve and a demand curve for each hour.

The results of the power market optimisation were fed into an interconnector assessment model (CARAMEL Light) that Pöyry developed for Ofgem, which calculated the socio-economic welfare impacts of each project considered. The calculations in both reports covered a period from 2022 and 2040, whilst the models were run for five spot years (2022, 2025, 2030, 2035 and 2040).

To assess the impacts on each interconnector and the interaction among multiple projects, the consultant conducted the market modelling analysis using two approaches:

- First additional (FA) approach: this approach examines the value of each proposed interconnector as if it is the only new interconnector to be built as scheduled. This represents the best case for an interconnector project as there would be no additional interconnection connecting after, which would reduce ('cannibalise') the project's congestion revenue.
- Marginal additional (MA) approach: this approach examines where a project is commissioning at the same time as the other projects assessed. This, in theory, represents the worst case for an interconnector project as there are additional projects connecting before, which would reduce the project's congestion revenue.

This approach is aligned with ENTSO-E's suggested PINT (Put IN one at the Time) and TOOT (Take Out One at the Time) methodologies, as suggested in their CBA guidelines.[38]

In the 2017 reports, three ad hoc and internally consistent scenarios (Base Case, High interconnector value and Low interconnector value) were developed, which aimed at assessing a reasonable range of outcomes for the overall economic benefit of new interconnection by examining a range of scenario drivers and assumptions. These scenarios were built using a selection of key assumption on commodity prices, electricity demand, capacity mixes from in-house analysis and different public and recognised sources:

- ENTSO-E visions developed for the Ten-Year Network Development Plan (TYNDP);
- National Grid Future Energy Scenarios (FES); and
- BEIS (previously DECC) Energy and Emissions Projections.

In the 2020 reports, an additional scenario was developed, called 'net zero scenario' in order to take a uniform approach on the decarbonisation commitment of the analysed countries and remove bias in the interconnector evaluation which depends on diverging decarbonisation agendas. The scenario was designed to show interconnector needs and value in a world where the assessed countries succeed in their efforts to reach deep decarbonisation of their economies. Arup notes that scenarios were consulted upon before running the SEW analysis underpinning both reports.

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[38] 3rd ENTSO-E guideline for cost benefit analysis of grid development projects (windows.net)

The interconnector baseline (i.e. the amount of interconnection capacity in place before commissioning of any new project) in the 2017 report was composed of all projects that were included in National Grid's interconnector register and/or were granted a C&F regime by Ofgem prior to Window 2. In the 2020 report, the baseline was composed of all projects that had received regulatory approval up to 2020.

Producing the system schedule

- **Dispatch of thermal plant.** All plants are assumed to bid cost reflectively and plants are dispatched on a merit order basis - i.e. plants with lower short-run variable costs are dispatched ahead of plants with higher short-run variable costs. This reflects a fully competitive market and leads to a least-cost solution. Costs associated with starts and part-loading are included in the optimisation. The model can also take account of all the major plant dynamics, including minimum stable generation, minimum on-times and minimum off-times.
- **Dispatch of hydro plant.** Reservoir hydro plants can be dispatched in two ways:
    - A perfect foresight methodology, where each reservoir has a one year of foresight of its natural inflow and the seasonal power price level and can fix the seasonality of its operation in an optimal way.
    - The water value method, where the option value of stored water is calculated using Stochastic Dynamic Programming. This results in a water value curve where the option value of a stored MWh is a function of the filling level of the reservoir, the filling level of competing reservoirs, and the time of year.
- **Variable renewable generation.** Hourly generation of variable renewable sources is modelled based on detailed wind speed and solar radiation data which can be constrained, if required, due to operational constraints of other plants or the system.
- **Interconnector flows.** Interconnectors are optimally utilised - this is equivalent to a market coupling arrangement.
- **Demand side response and storage**. Operation of demand side and storage is modelled in a sophisticated way, allowing simulation of flexible loads such as electric vehicles and heat while respecting demand side and storage constraints.

Power Price

The model produces a power price for each hour and for each zone (which may be smaller than one country, for example the different price-zones within Norway). The hourly power price is composed of two components:

- **Short-run marginal cost (SRMC).** The SRMC is the extra cost of one additional unit of power consumption. It is also the minimum price at which all operating plants are recovering their variable costs. Since the optimisation includes start-up and part-load costs all plant will fully cover their variable costs, including fuel, start-up, and part-loading costs.
- **Scarcity rent.** Scarcity rent is included in the market price - power prices are assumed to be able to rise above the short-run marginal cost at times when the capacity margin is tight. In each hour, the scarcity rent is determined by the capacity margin in each market. It is needed to ensure that the plants required to maintain system security can recover all their fixed and capital costs from the market.

Input Data

The power market modelling is based on the consultant's database of the European power market.

- **Demand**. Annual demand projections are based on TSO forecasts and the consultant's analysis. For the within year profile of demand, the historical demand profiles are used – for each future year that is modelled, demand profiles from a range of historical years are used.
- **Intermittent generation**. Historical wind speed data and solar radiation data are used as raw inputs. Consistent historical weather and demand profiles are utilised (i.e. both from the same historical year) which capture any correlations between weather and demand and can also example a variety of conditions – for example, a particularly windy year, or a cold, high demand, low wind period.

  For wind data, the hourly wind speeds at grid points on a 20km grid across Europe are used, at hub height. Hourly wind speed is converted to hourly wind generation based on wind capacity locations and using appropriate aggregated power curves. Detailed hourly solar data, sampled at a 5km resolution is converted to solar generation profiles based on capacity distributions across each country.
- **Fuel prices**. These are based on the consultant's database and are used in conjunction with BID3 to produce input fuel prices consistent with the scenarios developed.

Appendix B – NGET methodology used to determine economic impacts of interconnectors delivering ancillary services for Window 2

Frequency response

Recognising that interconnectors have the potential to increase the largest in-feed and out-feed loss on the system resulting in additional response requirements, NGET quantified the potential for interconnectors with Voltage Source Converter (VSC) technology to provide high and low frequency response and displace commercial frequency response.[39]

The potential savings involved are calculated as the difference between the cost of commercial frequency response and mandatory frequency response payments interconnectors are expected to make. To determine the interconnectors' operational profiles and frequency response requirements, NGET used its in-house tools for market modelling (ELSI, later on substituted with BID3) and network modelling (FRANK). NGET then considered two loading levels of frequency response to estimate the range of potential savings.

Black start capability

Black Start services are contracted to reenergise the network in block pieces joining up the sections until the entire network is reenergised. Services are contracted from an array of strategically located generators at specific locations, which are capable of re-energising the system.

Interconnectors which use VSC technology have the potential to offer Black Start capability and also potentially enable quicker restoration times for the transmission system (given there is no requirement to restore generation), providing access to a greater diversity of fuel sources improving overall resilience.

EWIC (East-West Interconnector) was the only interconnector at that time which offered black start services and was therefore used as an indication of the interconnector contract cost. An optimistic and pessimistic view of contract costs was then used to assess a range of potential savings from contracting interconnectors.

Reactive response

Because conventional power plants experience closure or lower rates of utilisation as more renewable energy source (RES) generation is deployed, the potential reactive response required to maintain a constant voltage level in the system is reduced at optimal locations. Interconnectors with VSC technology can alleviate reactive support capital expenditure by providing reactive compensation.

To assess the potential contribution of new interconnectors to reactive response, NGET conducted voltage studies on the local areas where the interconnectors were to be connected. In order to explore the range of reactive power support the interconnector could provide, the interconnectors were dispatched at 25%, 50% and 100% of their full capacities respectively and compared against the base network without the interconnectors.

The difference in additional reactive compensation required between the base network and the networks with interconnectors would normally be managed by installing specific kits of equipment. Hence, the monetary value for the reactive response of an interconnector with VSC technology is represented by the avoided investment requirements in such equipment.

Constraint management costs

When a network constraint occurs, the SO takes actions on the balancing market to increase and decrease the amount of electricity at different locations on the network to ensure network boundary limitations are not

[39] Low response responds to a downward deviation in the frequency (such as when a large in-feed trips) i.e. generation is lost on the system. High response responds to an upwards deviation in frequency (such as when a large out-feed trips) i.e. when a large area of demand is lost.

exceeded. Additional interconnector flow in an area can alleviate or contribute to network restrictions and impact on the constraint costs.

To forecast constraint costs, NGET used its in-house tool at that time, ELSI, to simulate the future operational constraints through optimisation of generation and storage resources dispatched to meet consumer demand requirements, firstly assuming that the system has infinite capacity (unconstrained dispatch). The model then considers the power flow restrictions on the network and re-dispatches generation where necessary to relieve instances where power transfer is greater than capability. The costs associated with moving away from the economic dispatch of generation is called the operational constraint costs and is calculated using the bid price and offer price (£/MWh).

The Present Value of Constraint Costs attributable to the new connection is calculated by subtracting the system-wide constraint costs without the new connection from the constraint costs with the new connection.

Appendix C – Hard-to-monetise impacts considered by Ofgem for Window 2

The hard-to-monetise impacts that Ofgem considered in Window 2 were:

1) Optionality: The evaluation of specific, realistic options that may be enabled or prevented by a decision.

2) Diversity and resilience: Resilience is defined as the energy system's capacity to tolerate disturbance and continue to deliver energy services to consumers. A resilient energy system can recover from shocks quickly and still meet energy needs even if external circumstances have changed. In general, diversity is considered to increase resilience.

3) Stress and security implications: This concerns the effect on security of supply; potential for extreme price and/or volatility in the market; and the UK's legally binding energy targets.

4) Learning by doing and supply chain development: This is the consideration that there can be potential savings in cost by one company/individual going through a process and passing that learning onto others. This can result in a more efficient process via sharing of learned efficiencies.

5) Pathways and lock-in: Pathways is the idea that past decisions or events can affect the likelihood of future decisions, i.e. one decision precludes another. Lock-in is where pathways make certain desirable options unachievable.

6) Natural assets and sustainability implication: This concerns the effect on consistency with UK 2050 targets; natural asset implications; and longer-term greenhouse gas (GHG) considerations.

Appendix D - Summary table of indicators from ENTSO-E CBA

Indicator	Unit	Description
B1. Socio-Economic Welfare (SEW)	€/y	The sum of the short-run economic surpluses of electricity consumers, producers, and transmission owners (congestion rent)
B2. Additional Societal benefit due to CO_2 variation	CO_2t and €/y	Change in CO_2 emission due to a new project or investment. Overlap between B1 and B2
B3. RES integration	MWh/y or MW	Reduction of renewable generation curtailment in MWh (avoided spillage) and/or the additional amount of RES generation that is connected by the project in MW. Avoided spillage is extracted from the studies for indicator B1.
B4. Non-Direct Greenhouse Emissions Benefit	t/y	Change in non-direct greenhouse emissions due to a new project or investment (CO, NO_2, SO_2 and particulates)
B5. Variation in Grid Losses	MWh/y MWh/y x mc(€)	Reflect the changes in transmission system losses that can be attributed to a project or investment.
B6. Security of Supply: Adequacy	MWh/y MWh/y x VoLL(€)	Ability of a power system to provide an adequate supply of electricity to meet the demand at any moment in time. Calculated using EENS.
B7. Security of Supply: System Flexibility	Various – not monetised	The capability of an electric system to face the system balancing energy needs in the context of high penetration levels of non-dispatchable electricity generation
B8. Security of Supply: System Stability Benefit	Not monetised	Indication of the change in system stability as a result of a reinforcement project. Various sub indicators: • Qualitative stability indicator • Frequency stability • Blackstart services • Voltage/reactive power services
B9. Avoidance of the Renewal/Replacement Costs of Infrastructure	€	Reduction of needed costs for replacing or upgrading existing infrastructure due to new projects or investments.
B10. Reduction of Necessary Reserve for Redispatch Power Plants	€/y	Change in needed reserves of redispatch power plants.

The CBA guidelines also present common principles and methodologies to be used in the necessary network studies, market analyses, and inter-linked modelling methodologies require to derive the indicators within each category described above. The ENTSO-E recognise that a fully monetised approach is not practically feasible as many benefits cannot be economically quantified in an objective manner. Hence, to ensure a full assessment of all the benefits, some of the indicators are quantified in their typical physical units (i.e. tons or GWh) or addressed qualitatively.

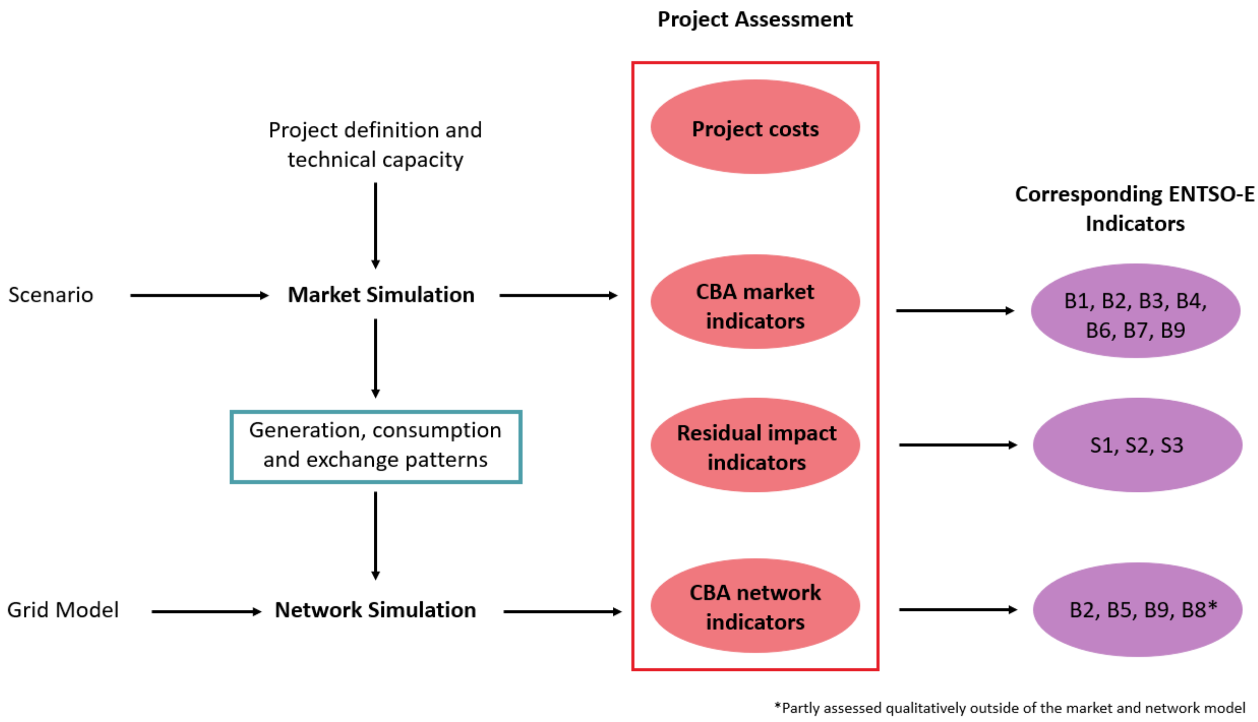

Figure 7 - Overview of modelling approach under ENTSO-E guidelines

The ENTSO-E then adopts a multi-criteria approach to combine the costs and benefits associated with a specific project in a standardised way. This allows the comparison of its full range of impacts, highlighting the different characteristics of each project and providing a complete set of information to decision makers. However, the CBA guidelines do not go further in suggesting how to reach a final decision based on the project assessment framework proposed, leaving decision makers the flexibility to develop the preferred approach to do so.

Appendix E - Assessment of flexibility under the ENTSO-E CBA guidelines and BEIS flexibility study

The system flexibility indicator of the ENTSO-E CBA framework seeks to capture the capability of an electric system to face the system balancing energy needs in the context of high penetration levels of non-dispatchable electricity generation. These changes are expected to increase in the future, which requires more flexible conventional generation to deal with the more frequent and acute ramping-up and ramping-down requirements.

Trading of ancillary services products through multi-bidding zones platform[40] - in particular balancing energy exchanges - is key to foster RES integration into power systems. The balancing services indicator is expected to show welfare net gains via the exchange of balancing energy and imbalance netting. Balancing energy refers to products such as Replacement Reserve (RR), manual Frequency Regulation Reserve (mFRR), and automatic Frequency Regulation Reserve (aFRR). The rationale being that exchanging balancing energy will permit cost savings and improvement in the net welfare via cost effective bids from interconnected markets displacing more expensive bids in the local balancing market.

This indicator is classified as a "non-mature" indicator in the ENTSO-E CBA framework. The comprehensive evaluation of balancing energy exchanges can solely be undertaken when platforms for exchanging balancing energy exist. Furthermore, ENTSO-E notes that there is a challenge when it comes to choosing the right balance between the complexity and feasibility of completing assessments, timescales, and resource levels. On the other hand, producing full models for balancing energy markets may be too time-consuming.

For these reasons, this benefit is addressed by qualitative assessment in the ENSTO-E CBA framework. The basic unit of measure ranges from 0 -meaning that the project has no (or marginal) impact on the Balancing Energy exchange indicator- to ++ when the project is deemed to have a large positive impact on the Balancing Energy exchange indicator.

An alternative way to assess flexibility is the approach followed by BEIS in its study of electric system flexibility.[41] BEIS has a much broader focus compared to ENTSO-E when it comes to assessing flexibility. BEIS calculates the impact of introducing flexible technologies on total system cost (£/MWh). BEIS calculated the impact on total system cost by using conjunctly their Dynamic Dispatch Model (DDM) and Distribution Networks Model (DNM) (used to assess network costs).

The total system cost (£/MWh) is divided into the following cost categories:

- Generation capital costs
- Generation operating costs
- Network costs
- Balancing costs
- Interconnector costs
- Other costs

Using the DDM, BEIS measured how system flexibility was impacting total system costs. The main insight is that system flexibility reduces system costs. It does this by reducing the curtailment of wind and solar and flattening demand for electricity, and therefore the overall capacity required.

[40] Such as EU imbalance netting, TERRE, MARIE, and PICASSO market. It is mandatory and required by Electricity Balancing Guideline (EBGL) to set up standard platforms for the exchange of balancing energy towards 2023.

[41] Appendix I: Electricity System Flexibility Modelling

Appendix F – Key modelling considerations for future needs case assessments

Based on its review of stakeholders' feedback, Arup has listed below key general modelling considerations to take into account in future needs case assessments.

Table 16 - Summary of Key Modelling Assumptions

Area	Suggestion
Inputs of the SEW analysis	Information such as capacity mix, demand, fuel & commodity prices, power station data should be taken from latest FES scenarios, and paired with the FES national equivalent or, if not available, with the TYNDP scenarios, based on the set convergence criteria such as -but not limited to- the speed of decarbonisation, whether net zero is achieved or not, level of decentralisation and other demand and supply drivers. It is strongly recommended to hold modelling workshops between Ofgem, its selected consultant and key stakeholders before running the SEW analysis to discuss and agree on key aspects such as, for example, required modifications of scenarios assumptions, identification of convergence criteria between FES and TYNDP scenarios, selection of high, base, and low case scenarios among those considered.
Weather years	If specific weather years are used, Ofgem or its consultant should communicate the set of weather years selected. The data should be publicly available for stakeholders to replicate the SEW analysis.
Interconnector baseline	In Arup's opinion, defining an interconnector baseline based on all projects built, under construction and with regulatory approval is a reasonable approach. The Ofgem's consultant should also run sensitivities to assess impacts of potential delays in the delivery of projects with regulatory approval, in recognition that not all projects considered in the baseline may be delivered on time. Following this approach means that there will be inherent incongruency issues between the interconnector baseline selected and the overall interconnector capacities of the FES and TYNDP scenarios used in the assessment, which are developed to be internally consistent. There are two potential options to address this issue: • Maintaining the initial interconnector baseline fixed during the time horizon considered. This in turn would require substantially manipulating other scenario assumptions (e.g. capacity mixes) to ensure internal consistency. This was the approach followed in the 2017 report. • Add interconnector capacities to the initial interconnector baseline during the time horizon considered to match the FES and TYNDP scenarios. This would limit the need to manipulate other scenario assumptions. This was the approach followed in the 2020 report. Independent of which option is selected, they should be discussed during the modelling workshops between Ofgem and key stakeholders.
Reference year and time horizon	The starting year of the SEW analysis should be the earliest connection year of the projects considered in any given application window. The SEW analysis should cover a minimum 25 years, considering that this equals the length of the C&F regime.
Modelling approach	In Arup's opinion, the FA-MA modelling approach used by Ofgem's consultant in the past is fit for purpose. However, considering that previous Ofgem's IPA decision relied on the results of the latter, Arup suggests running the SEW analysis using only the MA run. This would also avoid generating multiple data points to be considered under the new assessment framework. Alternatively, the analysis could be run using both the FA and MA approaches, however, the results from the FA could be assessed only if necessary, through a dedicated deep-dive analysis. Sensitivities reflecting potential delays in the delivery of the projects assessed in a given application window are recommended.

Geographical scope of the analysis	The geographical scope of the SEW analysis will be determined by the modelling capabilities of Ofgem's consultant. At a minimum, the analysis should cover GB, connected countries, and prospective connected countries. It is however recommended to extend the scope to a larger part of continental Europe, if possible.
Discount rate	The Ofgem's consultant should follow the Green Book's guidelines when selecting the discount rate to be used.
Unit	Indicators should be expressed as a yearly average value over the time horizon considered. If the modelling of every year is considered too cumbersome, spot year analysis should be used instead. If so, this should clearly be stated. All monetised indicators should be expressed in Net Present Value and in real terms.

Appendix G – Comparison of information required at IPA application submission stage from developers between Window 2 and Window 3

Window 2[42]	Window 3
Modelling study including cost-benefit analysis and social welfare modelling	Arup suggests making the submission of modelling study optional
Submission of indicative costs with a supporting explanation of how the costs have been estimated	No change
Submission of onshore network cost impacts from CION	No change
Justification of technical design, cables route, location of onshore connection points, technology choices, technical specifications (i.e. capacity, voltage, loss factors), project timelines, key milestone, risk management and strategy.	No change
n/a	Submission to NGESO of information regarding the ability of the project assessed to meet Grid Code ECC.6.3.19 GRID FORMING CAPABILITY
Qualitative evaluation of any additional hard-to-monetise benefits, costs and risks that aren't reflected in the modelling study.	No change

[42] Decision to open a second cap and floor application window for electricity interconnectors in 2016