Notes on Completion: Please refer to the appropriate NIA Governance Document to assist in the completion of this form. The full completed submission should not exceed 6 pages in total.

Network Licensees must publish the required Project Progress information on the Smarter Networks Portal by 31st July 2014 and each year thereafter. The Network Licensee(s) must publish Project Progress information for each NIA Project that has developed new learning in the preceding relevant year.

NIA Project Close Down Report Document

Date of Submission

Jul 2024

Project Reference Number

NIA2_NGESO015

Project Progress

Project Title

FIC (Future of Interconnectors)

Project Reference Number

NIA2_NGESO015

Project Start Date

July 2022

Project Duration

1 year and 1 month

Nominated Project Contact(s)

Magdalena Morenes

Scope

The scope of each phase of the project is clearly defined with specific deliverables and questions requiring an answer:

Phase 1 – Status quo and future net zero landscape

The market modelling and analysis conducted in this phase will aim at:

- Understanding current interconnector operational behaviour and business models
- Gathering insights into the energy system of each of the selected future energy scenarios and target years, in Britain and its neighbouring countries (e.g. supply and demand mix and patterns, flows and trends)
- Identifying which technologies and service providers will be available to meet the future needs of the system in the areas of flexibility, capacity adequacy and operability (e.g. how much capacity will be available to provide adequacy, other than the capacity provided by interconnectors? And from which sources?)

Phase 2 – Role of interconnectors in the net zero system

Through a deeper interrogation of the modelling data and expert engagement, this phase will provide a quantitative and qualitative assessment of the risks, opportunities, blockers and enablers related to interconnectors in the future energy scenarios analysed. Some of the questions that this phase will look into are:

- How could interconnectors provide support to the net zero system in terms of flexibility/capacity adequacy/operability? What potential barriers are there to this?
- What are the challenges brought by interconnectors in each of these areas? How can these be mitigated?
- Taking into consideration the needs of the system, what role should interconnectors take in flexibility/capacity adequacy/operability support?
- What will their impact be on carbon emissions?
- How would interconnector behaviour change if the GB wholesale market was reformed to include more locational pricing?
- How do we expect MPIs will behave relative to traditional interconnectors?

Phase 3 – Role of the ESO

Building on the conclusions delivered in Phase 2, this phase will identify a long-list of possible tools, levers or mechanisms that ESO and the wider industry could consider to lead to interconnectors benefitting the GB system more optimally. Identification of items on the long-list will not be constrained by existing commercial and regulatory frameworks or by existing organisational or institutional structures.

Because the project will model and analyse four different future energy pathways, we expect the results and findings to diverge between scenarios. There is even a risk that contradictory conclusions are reached between one scenario and another. Having visibility of this divergence will be essential in the development of recommendations.

Objectives

The main objectives of this work will be to:

1. Provide a clear insight into how interconnectors currently operate and behave in GB's energy system, establishing a baseline as a reference point for future looking analysis.
2. Examine the physical characteristics of GB and its neighbouring markets under selected Future Energy Scenarios (FES) cases for 2025, 2030 and 2035, investigating the requirement for and resource availability to provide flexibility, operability and adequacy needs.
3. Assess the potential role of interconnectors, and the opportunities and challenges they can offer, in a GB net zero system.
4. Analyse how interconnector behaviour might change under different circumstances such as the introduction of locational pricing in GB or the development of MPI models.
5. Identify potential barriers to and risks of provision of system services by interconnectors in a net zero system.
6. Identify a long-list of possible tools, levers or mechanisms that ESO and the wider industry could consider to lead to interconnectors benefitting the GB system more optimally

Success Criteria

This research project will lead to a better understanding of how interconnectors currently behave and operate in GB's energy system and how their contribution to the system might change as the number of interconnectors increases and the system evolves towards net zero. It will also enable the identification of innovative market solutions that could facilitate a more optimal use of interconnection.

The work will be developed with industry collaboration, and stakeholder acceptance and adoption of the analysis and results will be a key element of its success.

Within the stakeholders concerned by this work it is worth highlighting GB's neighbouring countries. Future interconnector operations will by nature depend not only on GB's market evolution, but also on the connecting countries electricity system changes. By sharing this analysis with its wider European counterparts, the ESO will take a leading role in shaping the conversation outside of the GB borders, and will contribute to the progression towards common net zero objectives

Performance Compared to the Original Project Aims, Objectives and Success Criteria

National Grid Electricity System Operator ("NGESO") has endeavoured to prepare the published report ("Report") in respect of FIC (Future of Interconnectors), NIA2_NGESO015 ("Project") in a manner which is, as far as possible, objective, using information collected and compiled by ESO and its Project partners ("Publishers"). Any intellectual property rights developed in the course of the Project and used in the Report shall be owned by the Publishers (as agreed between NG and the Project partners).

Project Overview

With 8.4GW of interconnector capacity currently, GB's electricity system could be on-track to achieve between 13 and 25GW by 2035. This will happen in a context of increased renewable energy sources (RES) both in the UK and its neighbouring markets, as countries strive to achieve net zero. The future GB electricity system will become highly weather dependent and difficult to forecast, creating challenges for the system operator.

The aim of this project is to understand the potential of interconnectors in supporting these challenges, looking specifically into:
how interconnectors contribute to the different dimensions of system operation (adequacy, flexibility, and operability);
how their behaviour and impact may evolve as we transition to a net zero system; and
what challenges/barriers may limit the system's ability to extract this value from interconnectors and how can these be removed/mitigated.

Project Plan

To achieve its objective, the project was divided in 3 phases, conducted by ESO's consultant-partner with close supervision from the ESO:

- Phase 1 – Status quo and future net zero landscape

The objective of this phase was to provide context and offer insight into how interconnectors currently operate and behave in GB's energy system and in the EU. The research done in this phase explored interconnector revenue streams, different market mechanisms, balancing mechanisms and regulatory regimes, both in the GB and the EU.

This phase also examined the physical characteristics of GB and its neighbouring markets under three selected years (2025-2030-2035), four Future Energy Scenarios (FES 2022) and five different weather patterns. The modelling results provided insights into expected future interconnector behaviour, including forecasted flow patterns (imports and exports) between GB and the connected countries.
Phase 1 was conducted between June and October 2022, producing two reports: "Status Quo" and "Future landscape of Great Britain & connected markets"

- Phase 2 – Role of interconnectors in the net zero system

Through a deeper interrogation of the modelling data and expert engagement, this phase focused on assessing the opportunities and risks related to GB interconnection in the areas of capacity adequacy, flexibility and operability. This phase also studied interconnectors' behaviour under different circumstances, such as under zonal/nodal pricing and Multi-Purpose Interconnector (MPI) models and evaluated the potential impact of interconnection on future carbon emissions.
This phase started in October 2022 and finished in February 2023, with all findings summarised in the report "Future role of interconnectors"

- Phase 3 – Role of the ESO / Long list of options

Building on the conclusions delivered in Phase 2 and the key issues it outlined, this phase identified a generic long list of possible tools, levers or mechanisms that ESO and/or the wider industry could consider leading to interconnectors benefitting the GB system more optimally.
The name of this phase was changed to "Long list of options" to reflect the fact that the solutions discussed are beyond the scope of work of the ESO.
The activities of Phase 3 started in February 2023 and were finalised in April 2023. The resulting report is called "GB interconnection: Long-list of options addressing future system challenges".

A final summary report and executive summary were also prepared and delivered in May 2023, compiling the key messages and findings of these three phases. After some consideration given to carrying on the analysis and extending the project, a decision was taken in 2024 to close the project and publish the closure report along with the executive summary. It is therefore worth noting that some of the information provided and terminology used was accurate at the time of writing but not anymore (i.e. the term MPI has since been replaced with OHA (Offshore Hybrid Assets); the level of interconnection has changed).

Project Activities

The project has used both qualitative and quantitative analysis to achieve its aims, including:

- quantitative review of current and historical interconnector performance;
- extensive stakeholder engagement across ESO and interconnector developers;
- analysis of the technology options available for the construction of interconnector assets and their capabilities in the provision of system services;
- qualitative assessment of market, regulatory and policy initiatives to identify key opportunities and risks of a system with a larger share of interconnectors; and
- market simulation modelling of ESO's Future Energy Scenarios to illustrate the shifts in interconnector operation as we transition to net zero.

Modelling activities were mainly carried out during phases 1 and 2 of the project.

In phase 1, information was provided on the decarbonisation pace of GB and its neighbouring countries, the different evolution of the energy mix and demand of these markets and how these differences will impact future electricity prices and therefore flows on the interconnectors. The modelling results reflect the variability of flows based on different weather conditions for the three years analysed, showing how this variability is visible mainly in the FES scenarios assuming a higher introduction of RES.

In phase 2, modelling was focused on understanding the future potential contribution of interconnectors to capacity adequacy, flexibility and operability, their impact on carbon emissions their behaviour under zonal pricing and an MPI model.

- Assessment of Adequacy. Capacity adequacy was defined in this study as the ability to ensure security of supply in periods of system stress, i.e. during peak demand with low RES output and critical outages. The main question that the modelling has helped to answer is: As interconnection to Europe increases, how reliant will GB be on power imports? To answer this question, the modelling looked into:

whether imports into GB are expected to grow during periods of system stress
the correlation in coincidental net peak demand in interconnected countries
the future evolution of the duration of peak periods as renewables displace conventional dispatchable generation

- Assessment of Flexibility. Flexibility in the context of this project has been defined as the ability to adjust consumption or production (export/import) of electricity in response to external market price signals. The question answered by modelling was: In times of excess supply and demand, how can interconnectors' flexibility alleviate energy imbalances through imports and exports? Modelling activities focused on:

future frequency of change of direction of flows on interconnectors
periods of spare capacity that could provide flexibility to the system
frequency of changes from full import to full export and vice versa

- Assessment of Operability. Operability in the context of this project refers to all aspects of operating the electricity system approaching/in real-time, including frequency response, reserve, thermal constraints, voltage, stability management and restoration. The question to answer was: What could interconnectors' contribution be to resolving the system's operability challenges brought by net zero? Modelling activities looked first into:

-how interconnectors will need to adjust their position in real time from day-ahead scheduling to make sure that operability constraints are met
-future thermal limitations of the transmission network

Two sensitivities were also then conducted to examine:
the operability impact of changing the landing point of an interconnector
whether allowing interconnectors to provide reserve, response and inertia products could potentially provide savings in the overall cost of procuring such operability services

- Assessment of Decarbonisation. Interconnectors open up markets to wider trading and ultimately impact on the marginal plant in a given power system. This analysis therefore concentrated on the changes in emissions resulting from the marginal plant influenced by interconnectors, providing information on how interconnectors may contribute in the future to carbon emissions in connecting countries as well as in GB.

- Assessment of Locational Pricing. An additional sensitivity was performed to study the impact on interconnector flows of the implementation of a simplified zonal market in GB. For this, 4 price zones were created, split by their transmission capability at the day-ahead stage. By comparing the flows in this zonal setup with the flows in a single market setup, it was possible to understand the difference in alignment between day-ahead and real time flows. Under the single market model setup, network constraints are not considered at the day-ahead stage and the balancing mechanism (BM) and ESO trades are used to make sure all operability constraints are met. Modelling demonstrated the impact of the creation of more pricing signals in the alignment between day-ahead and real-time flows.

The assessment of locational pricing also included the case studies of a zonal market (Norway) and a nodal market (PJM in the US), exploring the impact on interconnector behaviour of these arrangements.

- Assessment of MPIs. The fourth and final sensitivity delivered as part of the project was the study of different MPI configurations and their potential future impact on flows. The analysis compared a reference conventional interconnector (Nemo, 1 GW capacity, connecting GB to Belgium) with different MPI alternatives, all of them with 1GW transmission capacity and one or two 1GW offshore windfarms connected. Both 'Home Market' and 'Offshore Bidding Zone' market set-ups were modelled. The results of this sensitivity provided data on the frequency of maximum and zero flows and offered insights into the potential contribution of MPIs to adequacy, flexibility and operability.

Phase 3

No modelling was conducted during phase 3, but the analysis done in the first two phases of the project was used in this phase to identify the key issues to be addressed to achieve an optimal future utilisation of interconnectors. This was followed by the definition of a long list of possible tools, levers or mechanisms that ESO and wider industry could consider tackling these issues. The definition of the items on this long-list was not constrained by existing commercial and regulatory frameworks or by existing organisational or institutional structures, offering a comprehensive range of possibilities for further evaluation.

Required Modifications to the Planned Approach During the Course of the Project

The only change to the planned approach that has taken place in the course of the project has been the descoping of a dashboard including 8-12 visualisations in Power BI in Phase 2.

The objective of the dashboard was to provide longevity to the project by allowing ESO to conduct future analysis of interconnector behaviour across updated/different scenarios. The creation of this dashboard was dependent on direct communication with ESO internal modelling tool, which at the time of project scoping was BID3. The internal decision by ESO to change to another modelling tool provider (Plexos) following the start of the project increased the complexity of the dashboard design. An internal decision was therefore taken to descope this element of the project, as it will be more efficient and effective for ESO to design a dashboard from scratch directly in Plexos.

This change did not impact the project programme, as it was a standalone element of the scope. We requested the preparation of a Summary Report of the project. This was deemed necessary as all the analysis conducted in the project totals nearly 500 slides, and a summary report will play a key role in the dissemination of the project key findings and messages.

Lessons Learnt for Future Projects

The aim of the analysis conducted as part of this project was to understand what the future behaviour of interconnectors in GB might be and identify how to maximise their full potential to provide adequacy, flexibility and operability as we transition to net zero.
An extensive range of qualitative and quantitative research was done in phases 1 and 2 of the project. Phase 3 built then on the findings of this analysis to provide a structured overview of the different issues identified. This included:

- The definition of each problem statement
- A description of the “do nothing” situation: what would happen if current status quo is maintained while interconnector capacity keeps growing
- A description of the improvement potential

The outline of possible options to solve the problems identified
Phases 1 and 2 were developed considering the inputs of external stakeholders, including interconnector developers that provided their views on the opportunities and threats for their operations that the future energy system may bring.
Phase 3 on the other hand was developed through collaborative work between AFRY and ESO. No external engagement took place to develop the long list of options. A subsequent step of this work will therefore involve gathering feedback from the broader industry and key stakeholders to verify, develop and evaluate the suggested solutions. More in-depth analysis might also be needed when the benefits and drawbacks of the options are unclear or when more technical understanding is required.
This comprehensive research, consultation and evaluation process is not part of the FIC project deliverables. Its results should provide the necessary inputs to conduct a short-listing of solutions and provide recommendations. A well-structured roadmap will then follow, outlining a practical approach to effectively implementing the proposed solutions.
A key consideration and learning from this project that will be applied in future projects is the importance of defining a flexible scope, particularly in the extremely dynamic environment of electricity markets. Leaving flexibility to allow for a slight change of direction or a deep dive in a specific topic will always be useful to adapt to changes in the landscape and ensure the project remains relevant. This is of particular importance in long term projects with more than 1 year delivery period as this one was.

Note: The following sections are only required for those projects which have been completed since 1st April 2013, or since the previous Project Progress information was reported.

The Outcomes of the Project

in phase 1, the project has provided insights into the future behaviour of interconnector flows in different energy scenarios, reflecting how GB will transition from being a net importer of electricity to becoming a net exporter, and highlighting the differences between the regions connected.

In phase 2, the project has explored opportunities and challenges related to adequacy, flexibility and operability, providing the following key learnings:

- Adequacy: Interconnectors will remain an important source of energy into GB in periods of highest needs. Imports into GB are mostly expected to grow in absolute terms during periods of system stress, and the correlation between coincidental net peak demand (residual demand after accounting for variable RES) in GB and interconnected countries is expected to decrease. However, the duration of peak periods may grow in the future as renewables displace conventional dispatchable generation.
Interconnectors do not directly determine their own operating profile, hence they are not able to deliver firmness. Their ability to deliver during GB stress events will depend on:
The availability of excess generation capacity in Europe, which can be sensitive to some specific risks such as drought and nuclear outages
The markets' ability to efficiently deliver price signals that allow interconnectors to support efficient flows that reflect system tightness.
Maximising interconnectors' contribution to adequacy relies on efficient non-distorted price formation.

- Flexibility: Modelling results show that interconnector flows will remain dynamic, responding to the variability of renewable energy sources and the differing daily price patterns in connected countries across all scenarios. As interconnector capacity continues to increase, it is anticipated that periods of spare capacity will also grow, providing greater flexibility to the system. This is because the availability of unused interconnector capacity presents an opportunity to quickly respond to sudden shifts in market conditions on both sides of the connection.
The research highlights however the current inefficiencies in the trading over interconnectors in the intraday timeframe impacting the possibility to maximise interconnectors' flexibility capabilities.

- Operability: Interconnectors adjust their position in real time from day ahead scheduling to make sure that operability constraints are met at all settlement periods. These re-positioning actions are currently done through ESO trades, representing additional costs for the consumer. The analysis shows how scenarios with more interconnectors and RES capacity mean greater needs for re-positioning of interconnectors. The main driver for interconnector re-positioning is allowing thermal limits being met within the GB network.

The project demonstrates also how concentration and size of interconnectors can precipitate challenges for both stability and voltage of the network and the consequently importance of adequate network planning.
Finally, the analysis explores how interconnectors could provide operability services such as reserve, response or inertia if eligible to participate.

The assessment of decarbonisation, locational pricing and MPIs has provided the following insights:

- Decarbonisation: Imports to GB often results in increased emissions in neighbouring markets. Around half the time (scenario/year dependant) the marginal plant is not in GB and is quite often a thermal generator in continental Europe. This demonstrates how decarbonisation ambitions of different countries are becoming increasingly interdependent.

- Locational pricing: In a zonal market, redispatch volumes are expected to drop, as grid constraints are already to some degree being accounted for in the market scheduling. The pricing signals implemented by a zonal market would incentivise flows to be aligned between day-ahead and real-time, reducing the need for additional actions.

- MPIs: The analysis demonstrates that flows on MPIs are still driven by relative price differentials i.e. towards the market with the higher price, with no significant difference between "Home Market" and "Offshore Bidding Zone" setups. MPIs tested have:
similar / lower incidence of flows at max,
reduced cases of zero flows, and
greater frequency of partial flows relative to the conventional interconnector used as reference

Phase 3 of the project has identified 12 key issues that would need solving to maximise interconnectors' full potential in supporting the transition to net zero:

- Adequacy
Limited co-ordination with neighbouring system operators in network planning phase
Absence of coordinated interconnector development framework
Uncertain contribution in GB stress event
Uncertain behaviour of interconnectors in mutual stress events

- Flexibility

Non-harmonised day-ahead market designs
Inefficient intraday market arrangements
Onshore system constraints limit interconnector ramping potential

- Operability

Inability to fully utilize interconnectors' capabilities for real-time response
Inability to access available reserves in neighbouring countries in the balancing timeframe
Planning of interconnector projects does not properly reflect operational needs
Scheduling of interconnector flows does not account for system constraints in an efficient way
Bespoke interconnector trilateral arrangements are inconsistent causing operational complexity

Following the identification and definition of these key issues, the project has explored potential solutions that will need verification and refining in subsequent phases of the project to ensure recommendations for next steps can be made on solid grounds.

Subsequently, the business will undertake further and deeper analysis of these potential solutions. This will be done outside of this innovation project. We expect a prioritization exercise of key issues will first need to be conducted, to ensure resources are initially allocated to the areas that require strategic focus. Then the development of the solutions will be conducted through engagement with key stakeholders and the broader industry, with the aim of providing recommendations that will improve the effectiveness of cross-border flows in the net zero future. Finally, a well-structured roadmap will be prepared to outline a practical approach to effectively implement the proposed solutions.

Data Access

Details on how network or consumption data arising in the course of NIA funded projects can be requested by interested parties, and the terms on which such data will be made available by National Grid can be found in our publicly available "Data sharing policy related to NIC/NIA projects" and www.nationalgrideso.com/innovation.

National Grid Electricity System Operator already publishes much of the data arising from our NIC/NIA projects at www.smarternetworks.org. You may wish to check this website before making an application under this policy, in case the data which you are seeking has already been published.

Foreground IPR

The executive summary of the project will be published on the Smarter Networks Portal.

Planned Implementation

An extensive range of qualitative and quantitative analysis was done as part of the Future of Interconnectors (FIC) project, leading to the identification of key areas of focus that could maximise interconnectors' full capabilities and value in a GB net zero energy system.

Based on the evidence provided by the project and ESO's own internal insights, the ESO developed a Cross-Border Case for Change exploring areas that could unlock optimal contribution of cross-border flows in the areas of adequacy, flexibility and operability. This piece of work included a prioritisation exercise to shortlist the problems that should be focused upon first, performed through the assessment of each issue's urgency and its potential contribution to GB's energy trilemma.

As part of the FIC project, some potential options were identified to the issues highlighted, providing a high level description of their pros and cons. Further research will be needed to ensure we have a complete understanding of each option and make sure all avenues are explored. This deeper analysis will also need to take into consideration the ongoing market reform work being progressed through the Review of Electricity Market Arrangements (REMA) programme and other market design developments in Europe. Contributions from key stakeholders and industry will also ensure the development of solutions considers wider impacts.

This refining and verification work will lead to recommendations for future cross-border market arrangements which ought then to inform various decision-making processes led by ESO, the government, or regulatory bodies.

Other Comments

The Project outcomes and results contain confidential information and intellectual property rights that cannot be disclosed in this Report due to their proprietary nature. Should the viewer of this Report ("Viewer") require further details this may be provided on a case by case basis following consultation of all Publishers. In the event such further information is provided each and any Publisher that owns such confidential information or intellectual property rights shall be entitled to request the Viewer enter into terms that govern the sharing of such confidential information and/ or intellectual property rights including where appropriate formal licence terms or confidentiality provisions. Dependent upon the nature of such request the Publishers may be entitled to request a fee from the Viewer in respect of such confidential information or intellectual property rights.

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