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_NGET0002

Project Progress

Project Title

Role and value of electrolysers in low-carbon GB energy system

Project Reference Number

NIA2_NGET0002

Funding Licensee(s)

National Grid - Gas Transmission (GB wide)

Project Start Date

September 2022

Project Duration

1 year and 4 months

Nominated Project Contact(s)

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Scope

Task 1 [M1, M10 and M12]: Review of long-term scenarios for the UK

Subtask 1.1 [M1]: This activity will involve selecting a set of credible future development scenarios used in the analysis considering a range of scenarios from the CCC (including CCC sixth Carbon budget, the climate change risk assessment), BEIS (the climate change report just published), and National Grid FES to achieve net-zero 2050 targets.

Deliverable 1 [M1]: Report on set of decarbonisation scenarios for simulation studies.

Task 2 [M2-M4]: Update of the topology and parameters of the integrated model for electricity transmission planning

The objective of this task is to update the current model's topology and parameters against the selected set of scenarios.

Deliverable 2 [M4]: Report on integrated whole-system model for optimisation studies

Task 3 [M3-M11]: Optimal portfolio and system implications of Power-to-Gas under different scenarios

This task aims to study the system benefits of electrolysers from the whole system perspective with the primary focus on electricity transmission network and system balancing, while also identifying the infrastructure needed to support the transport of hydrogen and the requirement for hydrogen storage.

Subtask 3.1 [M4-M9]: System implications of electrolysers with focus on its impact on electricity transmission operation and development

The benefits and system impact of electrolysers across the whole-energy system will be quantified by comparing the modelling results for a system with and without electrolysers. The analysis will also include assessment of the optimal capacity, technology, and locations of electrolysers under different scenarios developed in Task 1 and using electrolysers for network congestion management to reduce network constraints and associated costs and need for network investment.

Subtask 3.2 [M7-M10]: Role and value of electrolysers in the context of ancillary services

The analysis will be conducted by enhancing the Imperial advanced frequency-secured Stochastic Unit Commitment (SUC) model, considering renewable generation uncertainty while ensuring supply security and frequency stability, taking into account the largest infeed loss and reduction in system inertia. The synergies and conflict between management of transmission network constraints and providing balancing services by electrolysers will be investigated.

Subtask 3.3 [M8-M11]: Transport of hydrogen and need for hydrogen storage

This task will investigate the feasibility of hydrogen transmission infrastructure and existing gas networks at various pressure tiers (i.e. high, medium and low pressure) to transport hydrogen to end user.

Deliverable 3 [M13]: Report on the benefits of optimal portfolio and system implications of electrolysers under different scenarios.

Task 4 [M9-M15]: Sensitivity studies

A range of sensitivity studies will be performed to analyse conditions that can affect the deployment of the electrolysers and, consequently, their system implications.

Deliverable 4 [M14]: Report on the drivers for the deployment of electrolysers and their whole system implications

Deliverable 5 [M15]: Integrated Electricity planning tool and user guide documents and demonstration.

Objectives

The main objective of this work is to identify the optimal locations for large-scale electrolysers to reduce system reinforcement and operational costs and quantify the benefits of multi-vector approach to reduce future network costs.

Success Criteria

The project will be considered successful if the developed model identifies a few optimal locations of large scale electrolysers in each selected decarbonization pathway.

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

NGET ("NG") has endeavoured to prepare the published report ("Report") in respect of f NIA2_NGET0002 Role and value of electrolysers in low-carbon GB energy system ("Project") in a manner which is, as far as possible, objective, using information collected and compiled by NG 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).
The Report provided is for information only and viewers of the Report should not place any reliance on any of the contents of this Report including (without limitation) any data, recommendations or conclusions and should take all appropriate steps to verify this information before acting upon it and rely on their own information. None of the Publishers nor its affiliated companies make any representations nor give any warranties or undertakings in relation to the content of the Report in relation to the quality, accuracy, completeness, or fitness for purpose of such content. To the fullest extent permitted by law, the Publishers shall not be liable howsoever arising (including negligence) in respect of or in relation to any reliance on information contained in the Report.

Project Overview
This project aims to analyse the benefits of linking electricity and hydrogen vectors from a whole-system perspective to determine the optimum capacity, location, technologies, and system benefits of electrolysers under different future development scenarios. The impact of power-to-gas on the whole energy system, particularly, integration of renewable generation (provision of system balancing and ancillary services), electricity transmission network operation and development, will be investigated. The project will develop an integrated whole system model to optimise the portfolio and locations of electrolysers considering several factors such as system constraints, end-use application of hydrogen, hydrogen transportation costs to end-use, and water availability to provide cost effective investments to achieve decarbonisation of energy networks.

Project Plan
The project started in June 2022.

- Deliverable 1: Report on set of decarbonisation scenarios for simulation studies (Month 1)
- Deliverable 2: Report on integrated whole-system model for optimisation studies (Month 4)
- Deliverable 3: Report on the benefits of optimal portfolio and system implications of electrolysers under different scenarios. (Month

10)

- Deliverable 4: Report on the drivers for the deployment of electrolysers and their whole system implications (Month 14)
- Deliverable 5: Integrated Electricity planning tool and user guide documents and demonstration. (Month 15)

Project Progress
2022/2023

- Deliverable 1: After a few months of delay caused by contract negotiations, the project started with a kick-off meeting in June 2022.

A report providing a set of decarbonisation scenarios for simulation studies was delivered on time.

- Deliverable 2: A report on integrated whole-system model for optimisation studies was delivered on time.

Deliverable 3: A report on the benefits of optimal portfolio and system implications of electrolysers under different scenarios was delivered on time.

2023/2024

Deliverable 4: Report on the drivers for the deployment of electrolysers and their whole system implications.
Deliverable 5: Integrated Electricity planning tool and user guide documents and demonstration.
The project has successfully conducted a significant set of studies, each of which holds crucial insights for our stakeholders. These studies include:

Analysis of the roles, benefits, and implications of using electrolysers for production of green hydrogen. It compares energy systems with and without electrolysers to determine their impact on system costs, power generation portfolios, network reinforcement etc. The study also identifies the optimal distribution of electrolysers across the Great Britain (GB) system and examines the conditions that would affect their demand, e.g., the cost of electrolysers and low-carbon technologies such as offshore wind and nuclear, dynamic and reversibility capability, gas price, interconnectors, and the level of system flexibility.
Analysis of the potential of electrolysers to deliver balancing services within the GB's electricity system. The studies assess their economic and operational benefits, including their impact on fuel cost savings, reduction in renewable energy source curtailment, and contribution to grid stability through frequency containment.
Studies about the integration and benefits of offshore electrolysers. This assessment provides insights into the varied implications of their integration into the broader energy landscape and the impact of electrolysers on the hydrogen network operation, including the management of line pack. The studies also investigate the role of electrolysers in supporting energy system operation during extreme weather events.
Analysis of the impact of different electrolyser deployment scenarios on the onshore electricity transmission system of GB. The studies evaluate many cases, including different electrolyser capacities and locations as well as onshore and offshore options.
The studies focus on the future GB net-zero (2050) energy system scenarios.
The transmission network planning tool (Holistic Network Design) has been delivered and the modelling details have been presented.

Next Steps
The work has been completed, while the outcomes of this project may trigger further discussions and corresponding analysis to inform future planning, operation, and commercial approaches, to facilitate optimal deployment of electrolysers into the system.

The imperial team will promote the dissemination of the studies through workshops/ conferences, journal publications and support any dissemination events organised by the National Grid.

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

Year 2022/2023:
There have been no changes to the scope or costs for this project. The project kick-off was delayed by 3 months due to delays in the contract negotiations phase. Therefore, the completion date has moved three months back.
Year 2023/2024:
No changes have been made to the scope and costs of the project. However, the final report submission has been delayed by three months due to the need for additional studies to cater for stakeholders' feedback.

Lessons Learnt for Future Projects

Year 2022/2023:

- Electrolysers provide flexibility to the system operator as a supplementary approach for system balancing by following the output of renewable energy sources such as wind and PV and to provide ancillary services such as frequency response and network constraint management services. As flexibility providers, electrolysers will compete with other flexibility technologies such as demand response, and/or energy storage.

- High gas prices will shift the hydrogen production from blue to green hydrogen. This will require additional investment in low-carbon generation and other supporting infrastructure such as hydrogen storage and networks. However, shifting to green hydrogen will also reduce the need for carbon storage and offsetting residual emissions from hydrogen production processes.

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.

Year 2023/2024:

The optimal integration of electrolysers requires a holistic approach as the technologies create complex interactions across electricity and hydrogen energy systems. The silo approach in deploying and operating electrolysers risks additional system integration costs resulting in a higher cost that needs to be paid eventually by the energy system users.
Many aspects around the location and operation of electrolysers need to be considered. For example, our studies have demonstrated that the allocation of electrolysers across the electricity transmission system of GB significantly impacts the investments in the onshore electricity transmission system of GB by 2050. The optimum locations of electrolysers are mostly driven by wind power, in Scotland, South Wales, Southwest, and Southeast England. Moreover, electrolysers have many functionalities that provide flexible services for the electricity and hydrogen systems, enabling more cost-effective integration and reducing the curtailment of low-cost intermittent renewable energy sources such as wind and solar power. Electrolysers also improve system balancing and can be dispatched for network congestion management by shifting energy transport from electricity to hydrogen, utilising the existing gas network capacity. Electrolysers also provide the capacity to produce green hydrogen from low-carbon sources interacting with other hydrogen production technologies from reforming or gasification processes. Therefore, future projects must consider the whole-system approach when analysing the benefits and impacts of electrolysers.
Enhanced engagement with key stakeholders from wider industry and academics will be beneficial to maximise the impact of research/studies on the market and policy development.

Dissemination
The key findings and results of the project will be disseminated via a conference or journal paper, and a dedicated dissemination workshop with key industry stakeholders in the summer.

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

Year 2022/2023:

- A set of decarbonisation scenarios for simulation studies was developed. The scenarios were divided into two categories: core and sensitivity scenarios. The core scenarios use the reference values of key parameters, while sensitivity scenarios alter the value of one or more parameters to identify the impacts of those parameters on the results. The core scenarios' outputs are used as references or counterfactuals when analysing the results from sensitivity studies.
- An integrated whole-system model was developed and the benefits of optimal portfolio and system implications of electrolysers under different scenarios were analysed. The system benefit from power-to-gas (P2G) is significant while there is lower flexibility in the system; it's less significant when flexibility is high because other flexibility sources such as demand flexibility, energy storage can reduce the need for P2G. It was also found that electrolysers facilitate higher penetration of wind and PV. Increased wind especially in the North given its high-capacity factor, will tend to increase the transmission network capacity requirement.

Year 2023/2024:

The project's key outputs consist of:

- A set of test scenarios.
- A modelling tool to analyse the impact of electrolysers on the onshore GB transmission system.
- A report containing a comprehensive set of results and analysis of the role and impact of electrolysers on the future GB energy system.

The key findings of the project are summarised as follows.

- Electrolysers reduce Renewable Energy Sources (RES) system integration costs by providing sector-coupling flexibility and ancillary services while producing green (low/zero carbon) hydrogen. They allow electricity to be converted to hydrogen and if stored efficiently, reduce the curtailment of renewable energy and improv the capacity factors of RES. With electrolysers, the volume of wind and solar (Photo Voltaic Cells) PV that can be integrated cost-effectively increases.
- Electrolysers can also support network congestion management; the network capacity released by electrolysers can support

connections of more low-carbon generation..
When the cost of green hydrogen production is higher than that of blue hydrogen, the system value of electrolysers lies in their contribution to flexibility. Therefore, in a system with sufficient flexibility sources such as demand response, energy storage, and interconnectors, the system benefits of electrolysers reduce; however, it can still provide alternatives for diversifying the hydrogen production sources. The results also imply that electrolysers compete not only with other hydrogen production technologies but also with other flexibility technologies.

- In a system with low flexibility, electrolysers can reduce the system costs by £2.16 bn/year. Most of the savings are in the avoided investment and operating cost for blue hydrogen production, reduction in carbon storage cost, and increased electricity exports while savings in transmission costs are relatively modest. To achieve those benefits, additional investment in low-carbon generation, electrolysers, and hydrogen storage are needed. The increased renewables also tend to increase electricity operating expenses or expenditure (OPEX) due to higher balancing requirements.
- While electrolysers contribute to increasing electricity consumption to displace some gas consumption in blue hydrogen production, they do not increase the electricity peak demand and, therefore, do not require increase in firm generation capacity. The increased electricity consumption from electrolysers is offset by a reduction in the electricity consumption used in the methane reforming processes.

Electrolysers improve the use of low marginal cost generation, such as renewables and nuclear. This benefit is higher in the low-flexibility case. For example, offshore wind curtailment drops from 8.3% in a system without electrolysers to 3.8% with electrolysers in the “Low flex” scenario. In the case with higher flexibility, the level of curtailment decreases from 4.7%–4.9% down to around 2%.

- Deploying electrolysers reduces hydrogen demand from the power sector since more renewables can be integrated and system flexibility is improved.

Electrolysers can reduce the production of blue hydrogen, but they cannot completely displace firm hydrogen production technologies such as Auto Thermal Reformers (ATR) with Carbon Capture, Utilisation and storage (CCS.) As a result, the capacity factor of ATR+CCS is lower when electrolysers are in use. This also leads to lower carbon storage requirements and residual emissions from reforming processes.

- Electrolysers do not affect the capacity factor of Hydrogen produced from Biomass Energy with CCS (BECCS H2). BECCS H2 has a specific role in offsetting carbon emissions.
- The impact of integrating electrolysers in the system on the hydrogen storage requirements varies in different cases. In “Low flex”, electrolysers drive 2.5 TWh more hydrogen storage. In “Mid flex”, the hydrogen storage requirement only increases by 290 GWh; in “High flex”, the storage requirement is 100 GWh less. This implies that electrolysers and hydrogen storage provide cross-vector coupling flexibility to both hydrogen and power systems.
- Increased capacity of electrolysers will require more hydrogen storage. Hydrogen storage facilitates the efficient operation of electrolysers.
- Locations of electrolysers are mostly driven by wind power, mostly in Scotland. Other locations include South Wales, Southwest and Southeast England.

The optimal capacity of electrolysers proposed in different cases varies. The capacity range in the hydrogen heating pathway (H2) is between 9.5 and 60 GW. The variation in the full electrification heating pathway is smaller, between 6.8 and 19.2 GW.

Key drivers for electrolysers in the Hydrogen heating pathway are high gas prices, low cost of electrolysers, low cost of offshore wind, high nuclear cost and lack of flexibility from demand response and distributed storage. The same drivers were observed in the electrification heating pathway, but the sensitivities to those factors are different. The highest driver is the lack of demand response and energy storage flexibility. Electrolyser deployment in hydrogen heating is more sensitive to gas prices than in electrification heating.

The following key messages are derived from investigating the role of electrolysers in maintaining grid stability by addressing challenges from reduced inertia:

- Electrolysers providing frequency response services significantly reduce grid operational costs, with potential savings up to £1.2 billion per year, but the value saturates when 30% of capacity (3GW) is reached due to competition with battery storage services.
- Electrolysers significantly reduce curtailment in renewable energy systems, absorbing excess electricity during peak production times and thus with potential savings up to 61 TWh per year.

By investigating the impact of offshore hydrogen production on electricity transmission and the overall operation of the hydrogen system, it has been demonstrated that:

- Hydrogen transmission and distribution enable hydrogen to be transported from production sites to load centres. Hydrogen can also be stored in pipelines; the hydrogen line pack provides intra-day flexibility to manage the challenges driven by renewable intermittency in the gas infrastructure. Flexibility from the hydrogen network should be operated in synergy with other flexibility technologies such as interconnectors, electricity storage and demand response technologies to support cost-efficient system operation and security.
- A future system with high renewables increases operational challenges as the studies reveal high swings in daily line pack, reaching 65 mcm/day and 75 mcm/day (up to 84% more than November 2021) in the Electrification and Hydrogen pathways, respectively.
- Offshore electrolysers can significantly reduce infrastructure reinforcement in both the hydrogen and electrification pathways by 23% and 19%, respectively. They use excess offshore renewable energy to produce green hydrogen, which can be transported via gas pipelines, thus decreasing the burden on electrical transmission networks.
- The use of offshore electrolysers significantly reduces the curtailment of renewable energy by 57%, enhancing the efficient use of offshore renewable resources for green hydrogen production and improving the energy system’s sustainability.

Sensitivity analysis has been carried out to investigate the impact that the allocation of electrolysers can have on investments in the onshore electricity transmission system of Great Britain in the year 2050. Five case studies have been conducted. These case studies share similar input data, with the key difference among them being the allocation of the electrolyser capacity across the electricity transmission system of GB in the year 2050. It is demonstrated that the allocation of electrolysers significantly impacts the required investments in the onshore electricity transmission system (assuming that the existing gas infrastructure can be used to transport hydrogen). The allocation of electrolysers on offshore will help reduce the onshore investment cost.

Recommendations for further work

Safety and regulatory compliance: Given the novel nature of hydrogen technologies, ensuring safety and compliance with local and international regulations is paramount. Future projects should prioritise developing robust safety protocols for electrolysers and associated technology, engaging with regulatory bodies early in the project lifecycle.

Further studies can also be conducted to identify how the electrolysers can be integrated in system planning and operational standards and whether the current market mechanism can provide appropriate signals to guide optimal investment and operation in electricity and hydrogen systems. It is crucial to accurately estimate and optimise the capacity of electrolysers with actual demand. The project highlighted a saturation point at 30% capacity due to competition with other technologies like battery storage. Future projects should consider detailed market analysis to optimise the scale of electrolyser deployment.

Regarding seasonal adjustments in production strategy, the effectiveness of using seasonal storage through hydrogen to manage RES availability for resilience enhancement, highlights the need for adaptive management strategies that consider seasonal and weather-related variations in energy availability. The uncertainty of hydrogen storage development, hydrogen network and RES variability could be captured in future work.

Data Access

- **Data Access Level**

Data for this project and all other projects funded under the Network Innovation Allowance (NIA), Network Innovation Competition (NIC) or the new Strategic Innovation Fund (SIF) can be found or requested in a number of ways:

- A request for information via the Smarter Networks Portal at: https://smarter.energynetworks.orgto contact select a project and click 'Contact Lead Network'. National Grid already publishes much of the data arising from our innovation projects here so you may wish to check this website before making an application.
- Via our Innovation website at: https://www.nationalgrid.com/uk/electricity-transmission/innovation
- Via our managed mailbox: box.NG.ETInnovation@nationalgrid.com

Foreground IPR

Foreground IPR will be created in relation to the test results of the methodology on the NGET network. The supplier will contribute the background IPR in the area of whole system model, whilst NGET will contribute background IPR with regards to the relevant electricity transmission domain knowledge used in the project.

Planned Implementation

There is a plan to disseminate the key results to core energy stakeholders.

Other Comments

No other comments.

Standards Documents