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LCP Delta

A holistic overview of the UK's offshore renewables potential, and international North Sea cooperation

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Dear Sue Harrison

A holistic overview of the UK's offshore renewables potential, and international North Sea cooperation

We have pleasure in enclosing a copy of our report in accordance with your instructions dated 22 September 2023. This document (the **Report**) has been prepared by Grant Thornton UK LLP (**Grant Thornton**) for the Department for Energy Security and Net Zero (**DESNZ**) (the **Addressee**) in connection with assessment of the value of the holistic operation in development of offshore renewable and low carbon technologies located in the North Sea (the **Purpose**).

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Scope of work and limitations

Our work focused on the areas set out in our scope of work, which is contained in our technical response to the Invitation to Tender.

There may be matters, other than those noted in the Report, which might be relevant in the context of the Purpose and which a wider scope assessment might uncover.

Forms of report

For your convenience, the Report may have been made available to you in electronic as well as hard copy format, multiple copies and versions of the Report may therefore exist in different media and in the case of any discrepancy the final signed hard copy should be regarded as definitive.

General

The Report is issued on the understanding that the management of DESNZ have drawn our attention to all matters, financial or otherwise, of which they are aware which may have an impact on our Report up to the date of signature of this Report. Events and circumstances occurring after the date of our Report will, in due course, render our Report out of date and, accordingly, we will not accept a duty of care nor assume a responsibility for decisions and actions which are based upon such an out-of-date Report. Additionally, we have no responsibility to update this Report for events and circumstances occurring after this date.

Notwithstanding the scope of this engagement, responsibility for management decisions will remain solely with the Addressee and not Grant Thornton. You should perform a credible review of the recommendations and options in order to determine which to implement following our advice.

Contacts

If there are any matters upon which you require clarification or further information, please contact Schellion Horn on schellion.j.horn@uk.gt.com.

Yours sincerely

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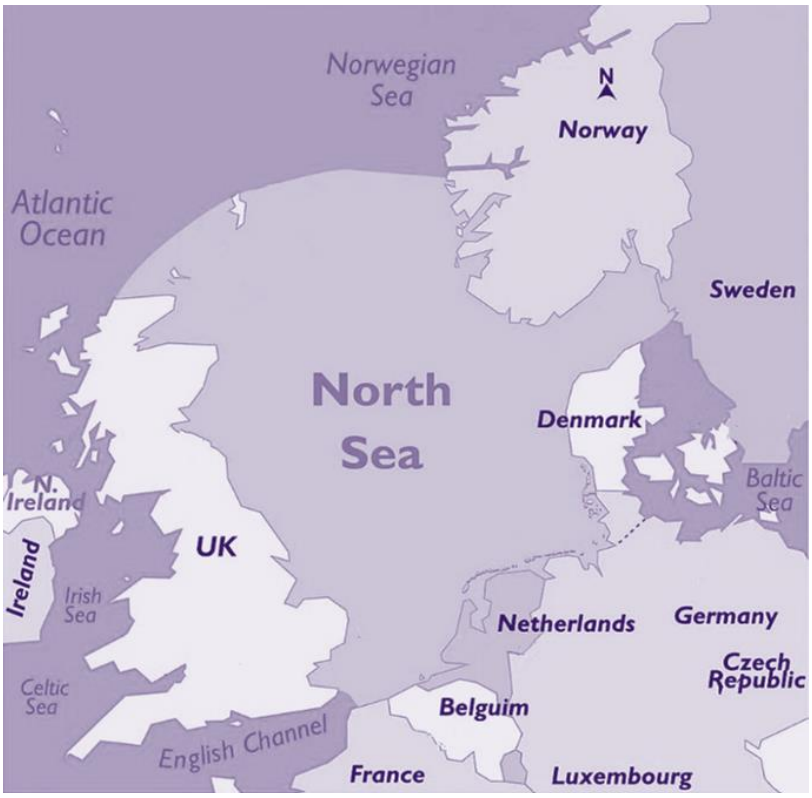
1 Executive Summary

1.1 Introduction

The development of a diversified renewables and low-carbon technologies portfolio in the North Sea is central to meeting the UK's target of Net Zero emissions by 2050. To meet this target, the DENZ recognises that offshore wind capacity needs to develop alongside low-carbon hydrogen and carbon capture utilisation and storage (CCUS) projects. To this end, the Sunak Government set an ambition of up to 50GW offshore wind capacity, 18GW of electricity interconnector capacity with the ambition to build the first multipurpose interconnector (MPI), up to 10GW of low carbon hydrogen production, and to capture 20-30MtCO_2 per year.

The North Sea (shown in **Figure 1**) is home to the UK's oil and gas industry, offshore windfarms, electrical transmission interconnectors. Recognising its vast potential, initiatives aimed at promoting a more coordinated and holistic approach to North Sea development began to emerge in 2011, when DECC (now DESNZ) and Ofgem jointly launched the Offshore Transmission Coordination Project to ensure timely and coordinated development of the grid. In 2020, BEIS (now DESNZ) launched the Offshore Transmission Network Review which concluded in 2022.

Figure 1: The North Sea and surrounding countries



Source: North Sea - WorldAtlas

The purpose of the review was to ensure that the transmission connections for offshore wind generation are delivered most appropriately. This brought together key stakeholders involved in the timing, siting, design and delivery of offshore wind, to consider all aspects of the existing regime and how this influences the design and delivery of transmission infrastructure.[1] The core outcome of the report was the Holistic Network Design (HND) published by the Electricity System Operator (ESO), now the

[1] Source: Offshore transmission network review - GOV.UK (www.gov.uk)

National Energy System Operator (NESO)[2], in July 2024 with the proposal of offshore wind connections from a radial (point-to-point) approach for individual projects, to a more coordinated one.[3]

While continuing with initiatives to adopt a holistic approach in renewables infrastructure development in the North Sea at the domestic front, the Government also recognises the need for international cooperation with countries sharing the North Sea waters. This was already part of the European Union (EU) objective of supporting collaboration among the North Sea countries[4] towards unlocking the region's full potential for renewable energy production including development of an offshore grid.

In 2016, a joint political declaration established the North Seas Energy Cooperation (NSEC), which aims to facilitate cost-effective deployment of offshore renewable energy, in particular wind, and to promote interconnection between countries in the region.[5] The UK was part of this declaration until its formal withdrawal from the EU on 31 January 2021. To continue with this cooperation, in December 2022, the UK signed a Memorandum of Understanding (MoU) with NSEC members, renewing the cooperation. Under the MoU framework, the UK is invited to attend meetings of all the NSEC workstreams that cover specific topics or projects of "direct common interest" to the UK and NSEC participants. Additionally, the UK further enhanced its bilateral cooperation through initiatives such as the UK-Belgium MoU, UK-Norway Interconnection Treaty, UK-France Partnership, the UK-Denmark MoU and the UK-Ireland MoU.

Such MoUs with neighbouring NSEC countries focus on cooperation in the energy transition, covering a range of policy areas and technologies. It emphasises the importance of voluntary cooperation, with the aim of securing a sustainable, secure and affordable energy supply for the North Sea countries. This supports the vision of international corporation in the Sunak Government's Integrated Review Refresh 2023.

The most recent development in the direction of international cooperation was the signing of the Ostend Declaration, in April 2023 by heads of governments and energy ministers in the region including the British Prime Minister, setting out a combined ambition of at least 120GW offshore wind and 30GW of renewable hydrogen production by 2030. It makes clear that the North Sea has the potential to be the green power plant of Europe and UK will need to build infrastructure connecting it to neighbouring markets and work with its North Sea neighbours.

1.2 Objectives of this report

This report focuses on identifying the economic opportunities that may arise should the UK adopt a holistic approach in the North Sea through domestic coordination between relevant stakeholders and international cooperation between the NSEC countries for the development of four energy asset types – interconnectors, offshore wind, CCUS and low carbon hydrogen.

A combination of quantitative and qualitative approaches was used to meet the objectives of this project which are:

- To understand the **economic** and **commercial** value to the UK from the holistic interaction between offshore wind, electricity transmission infrastructure (including interconnectors), low carbon hydrogen and CCUS.
- To **address a gap in understanding** of how UK ambitions and associated economic gains of expanding UK energy infrastructure in the North Sea are: i) dependent on and ii) are amplified by cooperation among countries around the North Sea.

1.3 Methodology

To meet the objectives of this project, a combination of quantitative and qualitative approaches was adopted. The qualitative approach was built on an extensive literature review of existing research including academic papers, articles and policy documents on international cooperation in the North Sea,

[2] Note: The ESO will be known as the National Energy System Operator (NESO) from October 2024.
[3] Source: [Offshore Transmission Network Review: summary of outputs - GOV.UK (www.gov.uk)]
[4] North Sea Countries include members of the NSEC: Belgium, Denmark, France, Germany, Ireland, Luxembourg, the Netherlands, Norway, Sweden and the European Commission.
[5] Source: [The North Seas Energy Cooperation (europa.eu)]

focusing on the common objective of achieving accelerated energy transition. The following three deployment scenarios were developed for the four key energy asset types in the North Sea, which include offshore wind, interconnectors, CCUS facilities and low carbon hydrogen production:

- **Scenario 1** serves as the baseline scenario. It is an illustrative scenario that assumes that planning and development of the four energy asset types is expected to take place as per current UK policy objectives and approaches. The baseline scenario has two sensitivities; the first being the Known Policy scenario, which outlines what the electricity sector and underlying market conditions would look like if the Government made no further policy interventions beyond what has already been implemented, adopted or planned and second is the Net Zero High scenario, based on power sector scenarios from the Dynamic Dispatch Model (DDM) [6] – the core energy systems model used by DESNZ. The latter is the higher demand scenario with an overall indicative power demand of 765 TWh, which assumes nearly all road transport to be electrified with higher overall traffic levels and higher electrification of heat in homes and businesses.
- **Scenario 2** is the holistic domestic scenario. It assumes a holistic approach to strategic planning for the four energy asset types by means of coordination between domestic developers such as the Government, the Crown Estate and network operators.
- **Scenario 3** is the holistic international scenario. It assumes that a holistic approach is adopted between domestic developers and developers in other North Sea countries. This would support the development of a cross-border offshore energy systems integration between the UK and other North Sea countries and accelerate the energy transition.

The above three scenarios formed the basis for assumptions in the network and power market zonal modelling approach which were used to assess the potential impact that the development of the four key energy asset types in the North Sea can have on both GB and connected European systems.

To assess the impact on the system across the two test scenarios compared to the baseline, LCP Delta's EnVision modelling framework was used, which stochastically simulates power markets and network utilisation across Western Europe. This modelling framework has been used extensively by LCP Delta in projects for DESNZ, including in the assessment of benefits of improved locational signals.

The key outputs of the modelling are the changes in system and consumer costs between the greater coordination and cooperation scenarios and the counterfactual. The approach to system costs uses the framework for Whole System Costs that was developed in 2015 between LCP, Frontier Economics and UK Government, and incorporated into the DDM for use in Government power sector impact assessments and Value for Money assessments.

System costs represent the costs of building, operating and maintaining the power system that include costs of generation, carbon, capital expenditure (capex), fixed operational expenditure (opex), network and interconnector costs. Consumer costs represent wholesale electricity costs and policy support costs such as Contract for Difference (CfD) and Renewables Obligation to Contracts (ROC) schemes for new and existing plants.

The cost changes have been presented in the form of 'benefits'; this is positive for savings and negative for an increase in costs. They are modelled in most detail for GB[7], with indicative changes for foreign markets in the holistic international coordination approach presented in scenario 3.

An Impact Analysis was used to analyse the wider impacts of the holistic approach that included both qualitative and quantitative assessments. The social and economic impacts were estimated through gross job supporting the developments and gross value added (GVA) respectively. To estimate the GVA, the job estimates were used and the appropriate GVA per worker was applied from two ONS sources – the Environmental Goods and Services sector database and the Productivity database by industry and region to provide a range of potential GVA that could be added to the economy under the scenarios.

[6] A comprehensive fully integrated power market model by DESNZ covering the GB power market over the medium to long term.

[7] In the report we have used Great Britain (GB) when referring to all modelling scenarios and outcomes and United Kingdom (UK) when referring to policies and benefits.

1.4 Key findings

1.4.1 Potential for significant system and consumer cost savings

Under the assumption of holistic domestic coordination in Scenario 2, the quantitative modelling shows a potential of approximately £21 billion and £14 billion system and consumer benefits respectively when compared to the Known Policy baseline. These benefits increase to approximately £24 billion and £18 billion when the holistic approach is extended internationally in Scenario 3. In terms of CO_2 emissions, a reduction of approximately 37 MtCO2 is expected with greater coordination with a reduction of 46 MtCO2 expected with greater international cooperation. These results, shown in **Table 1** below, demonstrate that the UK would benefit significantly from the coordinated development of these assets, and even more so if combined with international cooperation.

Table 1: Benefits of a holistic domestic and international approach under Known Policy baseline

Scenario	System benefit	Consumer benefit	Total CO_2 reduction
	NPV £billion (2023 real)		$MtCO_2$
Scenario 2 - Holistic Domestic Coordination	21.3	14.6	37.1
Scenario 3 - Holistic International Coordination	24.3	18.3	46.3

Source: Grant Thornton analysis

When compared to the Net Zero Higher baseline, there are also significant expected benefits to greater coordination and cooperation. This is shown in **Table 2** below. These benefits are lower than when compared to the Known Policy baseline. There is a potential of approximately £16 billion and £6 billion in system and consumer benefits respectively, under the assumption of holistic domestic coordination. When the holistic approach is extended internationally, system benefits are approximately £12 billion, which is half of what is expected under Known Policy baseline and lower than what is expected from holistic domestic coordination only. The consumer benefits increase to approximately £12 billion, which is lower by approximately £6 billion when compared to Known Policy baseline.

This difference in outcomes arises because the Net Zero Higher baseline assumes all policies to meet Net Zero are in place and therefore has a higher base of renewables than that in the Known Policy baseline assumptions. Therefore, the magnitude of the net benefits is lower in the former than the latter of the baseline assumptions.

Table 2: Benefits of a holistic domestic and international approach under Net Zero Higher baseline

Scenario	System benefit	Consumer benefit	Total CO_2 reduction
	NPV £billion (2023 real)		$MtCO_2$
Scenario 2 - Holistic Domestic Coordination	15.6	5.8	(1.9)
Scenario 3 - Holistic International Coordination	11.6	12.3	(0.4)

Source: Grant Thornton analysis

1.4.2 Positive economic impact and higher labour productivity

The impact analysis shows an increase in Gross Value Added (GVA) to the economy as a result of the holistic approach for both the Known Policy and Net Zero Higher baselines. Increased international cooperation is expected to drive greater efficiency, which would lead to increased energy production and potentially higher labour productivity. Compared to the two baselines, there is a higher GVA potential, and possibly fewer jobs would be needed where there is greater cooperation and coordination. This analysis captures only direct jobs and there is likely to be a substantial number of indirect and induced jobs in the baseline in the relevant supply chains. Induced roles include jobs that are created due to increased employment in the local economy, which is expected to have a multiplier effect on local businesses. This is particularly true for CCUS and hydrogen, which operate in regional clusters and is likely to positively impact the local economy because of increased demand for local goods and services from workers.

Table 3: Potential gross jobs supported under a holistic approach

	2030	2050	2030	2050
	Known Policy		Net Zero Higher	
Baseline	60,500	42,100	66,400	134,900
Scenario 2	51,000	35,800	56,300	115,800
Scenario 3	51,000	35,800	56,400	115,900

Source: Grant Thornton analysis

Table 4: Range of GVA potential under a holistic approach

	2030 (£ billion)	2050 (£ billion)	2030 (£ billion)	2050 (£ billion)
	Known Policy		Net Zero Higher	
Baseline	6.63 - 36.47	4.61 - 25.15	7.28 - 38.39	14.78 - 67.77
Scenario 2	6.64 - 36.51	4.62 - 25.18	7.32 - 38.65	14.81 - 67.96
Scenario 3	6.66 - 36.58	4.63 - 25.24	7.33 - 38.71	14.82 - 68.01

Source: Grant Thornton analysis

1.4.3 Environmental benefits are expected, including better outcomes for marine life

The main environmental benefit arises from emission reduction under both scenarios due to higher deployment of offshore wind. As for the system and consumer costs savings, the savings in emissions are significantly higher in the Known Policy scenario than the Net Zero Higher baseline, which assumes a higher level of offshore wind capacity. There are also potential positive impacts to the geographic environment in the North Sea with a holistic approach to planning and development of the four energy assets. Coordination and cooperation are expected to require fewer interconnectors as a result of moving away from point-to-point to multipurpose interconnectors (MPI). Other risks to the marine environment that may arise from CO_2 leakage from CCUS projects (such as the creation of artificial reefs) are expected to be less because duplication of infrastructure is avoided when a more holistic approach is adopted.

1.4.4 A wide range of other benefits are expected

The other wider benefits from a holistic coordinated approach are increased security of supply for energy due to diversification of sources, greater technological innovation, faster roll out of projects, and potential reduction in wholesale energy prices due to increased competition.

2 Introduction

2.1 Purpose of the report

The Department for Energy Security & Net Zero (DESNZ) has commissioned Grant Thornton to provide a holistic overview of the UK's offshore renewables and low carbon technology potential and whether this potential can be increased with international North Sea cooperation.

The objectives of the project are twofold:

- To understand the economic and commercial value to the UK from the interaction between offshore wind, electricity transmission infrastructure (including interconnectors), low carbon hydrogen and CCUS holistically, particularly considering how the latter two is expected to increase in importance over the next decade.
- To address a current gap in understanding of how UK ambitions and associated economic gains of expanding UK energy infrastructure in the North Sea are: i) dependent on and ii) are amplified by cooperation among countries around the North Sea.

In achieving these objectives, the report addresses the following research questions that were specified by DESNZ:

Identify the economic opportunities of a holistic approach in the North Sea

- Assessment of the critical success factors in realising the UK's separate targets in each of the four types of infrastructures, as set out in the Background section below. This covers policy, regulatory, environmental, and social considerations (including spatial distribution), and technological or economic factors.
- Determination of the extent to which this holistic approach can help meet UK's overall North Sea targets (set out in the Background section) and highlight the interdependencies of these targets and their consequences.
- Identification and assessment of the economic and commercial opportunities to 2050 and beyond for the UK associated with North Sea green transition. The factors to be considered are technical, economic, environmental and strategic and the assessment in terms of numbers of jobs created development of relevant skills or £billon of additional investment.

Determine the value of North Sea cooperation

An Impact Assessment of international cooperation with North Sea partners on building UK's offshore infrastructure such low carbon hydrogen production, CCUS deployment, electricity transmission infrastructure and centralised energy hubs (energy islands). This includes the following parameters:

- Development of scenarios for each of the above technologies up to 2050 and beyond, through the holistic approach.
- Quantitative analysis of system and consumer benefits through power market modelling based on scenarios developed.
- Quantitative analysis involving job creation, £ billion of investment and contribution to total UK GW/MTCO_2 development by 2030 and 2050.
- Quantitative assessment of the potential value of cooperation benefits for UK's North Sea partners regarding different aspects of international cooperation.

- Stakeholder engagement assessing the nature, extent and policy consequences of technical, diplomatic and commercial uncertainties and risks.

2.2 Background

The development of a diversified renewables and low-carbon technologies portfolio in the North Sea is central to meeting the UK Government's target of Net Zero emissions by 2050. To meet this target the Government recognises that offshore wind capacity needs to develop alongside low-carbon hydrogen and carbon capture utilisation and storage (CCUS) projects.

Over the years, successive governments have set out their strategic priorities for the energy sector in several papers including the Energy White Paper (2020), Ten Point Plan for a Green Industrial Revolution (2020), Net Zero Strategy (2021), British Energy Security Strategy (2022), Energy Security Plan (2023), Net Zero Growth Plan (2023) and Transmission Acceleration Action Plan (2023).

The North Sea is home to the UK's oil and gas industry, offshore windfarms, electrical transmission interconnectors along with shipping lanes that compete for space. The forward-looking decarbonisation ambitions is expected to further include low carbon hydrogen production facilities, CCUS sites and further interconnections with power grids of neighbouring countries.

Initiatives aimed at promoting a more coordinated and holistic approach to North Sea development began to emerge in 2011, when the Department of Energy & Climate Change (DECC, now DESNZ) and Ofgem jointly launched the Offshore Transmission Coordination Project to ensure timely and coordinated development of the grid. It considered whether additional measures would be required to deliver coordinated networks through the competitive offshore transmission regime and, if so, how these measures might work in practice. The benefits highlighted were lower overall capital costs, potential reduced environmental impacts and planning related delays thereby ensuring a long-term sustainable pathway.[8]

In 2020, BEIS (now DESNZ) launched the Offshore Transmission Network Review which concluded in 2022. The purpose of the review was to ensure that the transmission connections for offshore wind generation are delivered most appropriately. This brought together key stakeholders involved in the timing, siting, design and delivery of offshore wind, to consider all aspects of the existing regime and how this influences the design and delivery of transmission infrastructure.[9] The core outcome of the report was the Holistic Network Design (HND) published in 2022 by the Electricity System Operator (ESO), now the National Energy System Operator (NESO) [10] with the proposal of moving offshore wind connections from a radial (point-to-point) approach for individual projects, to a more coordinated one.[11]

The HND is being developed over time into a Centralised Strategic Network Plan (CSNP) which will adopt a *"broad, whole energy system view to transforming the pace and scale"* of network planning. For electricity, this will integrate onshore and offshore transmission networks as well as cross-border interconnectors and offshore hybrid assets. The precursor to the CSNP, known as the Transitional Centralised Strategic Network Plan (tCSNP), has been published and will sit under the Strategic Spatial Energy Plan (SSEP) being developed by the Government and the NESO.

While continuing with initiatives to adopt a holistic approach in renewables infrastructure development in the North Sea at the domestic front, the Government also recognises the need for international cooperation with countries sharing the North Sea waters. This was already part of the European Union's (EU) objective of supporting collaboration among the North Sea countries[12], with an eye towards unlocking the region's full potential for renewable energy production. This includes development of the offshore grid.

In 2016, a joint political declaration established the North Seas Energy Cooperation (NSEC), which aims to facilitate cost-effective deployment of offshore renewable energy, in particular wind, and to promote

[8] Source: Offshore Transmission Coordination Project Conclusions Report, March 2011
[9] Source: Offshore transmission network review - GOV.UK (www.gov.uk)
[10] Note: The ESO will become will be known as the National Energy System Operator (NESO) from Summer 2024.
[11] Source: Offshore Transmission Network Review: summary of outputs - GOV.UK (www.gov.uk)
[12] North Sea Countries include members of the NSEC: Belgium, Denmark, France, Germany, Ireland, Luxembourg, the Netherlands, Norway, Sweden and the European Commission.

interconnection between countries in the region.[13] The UK was part of this declaration until its formal withdrawal from the EU on 31 January 2021. To continue with this cooperation, in December 2022, the UK signed a Memorandum of Understanding (MoU) with NSEC members, renewing the cooperation. Under the MoU framework, the UK is invited to attend meetings of all the NSEC work streams that cover specific topics or projects of *"direct common interest"* to the UK and NSEC participants. Additionally, the UK further enhanced its bilateral cooperation through initiatives such as the UK-Belgium MoU, UK-Norway Interconnection Treaty, UK-France Partnership, the UK-Denmark MoU, the UK-Germany energy and climate partnership and the UK-Ireland MoU.

Such MoUs with neighbouring NSEC countries focus on cooperation in the energy transition, covering a range of policy areas and technologies. They emphasise the importance of voluntary cooperation, with the aim of securing a sustainable, secure and affordable energy supply for the North Sea countries. This supports the UK Government's 'reset' of relations with Europe.

The most recent development in the direction of international cooperation was the signing of the Ostend Declarations in April 2023, by heads of governments and energy ministers in the region including the British Prime Minister, setting out a combined ambition of at least 120 GW offshore wind and 30 GW of low carbon hydrogen production by 2030. It makes clear that the North Sea have the potential to be the green power plant of Europe and UK will need to build infrastructure connecting it to neighbouring markets and work with its North Sea neighbours.

2.3 The meaning of cooperation and a holistic approach

There are two steps to coordinated development of renewable assets in the North Sea. First is the coordination among domestic stakeholders within UK as proposed in the Energy White Paper (2020). Examples include the establishment of a Ministerial Delivery Group, which would bring together the relevant Government departments to oversee the expansion of renewable power in the UK. This group will provide the cross-Government coordination and collaboration necessary to achieve the UK's ambition for renewable electricity. Another example is the North Sea Transition Deal aimed at delivering commitments set out in the oil and gas chapter of the Energy White Paper, which includes further commitments to support the development of offshore wind, low carbon hydrogen, and CCUS technologies in the North Sea.

The second step is the expansion of this coordinated approach beyond UK borders towards cooperation with the neighbouring countries in the North Sea who are members of the NSEC.

In summary, both domestic and international coordination include cooperation in:

- Joint infrastructure projects.
- Coordination of maritime spatial planning.
- Financing and support schemes.
- Regulatory frameworks and trading arrangements.
- Supply chains.

Therefore, at both the domestic and international levels, involving other North Sea countries, a holistic approach would require an integrated strategy to wider network planning around offshore renewables. Applying this across generation, transmission and storage for all renewable energy sources and low carbon technologies can help the UK realise economic and commercial value, whilst also reaching Net Zero targets. By working together, stakeholders in the North Sea can help to ensure that it remains a vital source of energy for the UK, while also supporting the transition to a low-carbon energy system.

[13] Source: [The North Seas Energy Cooperation (europa.eu)]

3 Scenario development

3.1 Introduction

This section defines three scenarios for how UK offshore renewables infrastructure and low carbon technologies could be deployed to achieve Net Zero. The scenarios have been used to test the hypothesis that a more holistic network design for the offshore wind, low carbon hydrogen, CCUS and interconnectors could deliver additional economic and commercial value for the UK. The following section discusses the underpinning policy assumptions for each scenario, and how they differ from each other. This includes assumptions on the development of each of the four key asset types, how they map across the three scenarios and the rationale for their inclusion.

3.2 Scenario overview

The three scenarios are:

- **Scenario 1** serves as the baseline scenario. It assumes that planning and development of the four energy asset types is expected to take place as per current UK policy objectives and approaches. The baseline scenario has two sensitivities; the first being the Known Policy scenario, which outlines what the electricity sector and underlying market conditions would look like if the Government made no further policy interventions beyond what has already been implemented, adopted or planned and second is the Net Zero Higher demand scenario with a higher power demand. The latter assumes nearly all road transport to be electrified with higher overall traffic levels and higher electrification of heat in homes and businesses.
- **Scenario 2** is the holistic domestic scenario. It assumes a holistic approach to strategic planning for the four energy asset types by means of coordination between domestic developers such as the Government, the Crown Estate and network operators.
- **Scenario 3** is the holistic international scenario. It assumes that a holistic approach is adopted between domestic developers and developers in other North Sea countries. This would support the development of a cross-border offshore energy systems integration between the UK and other North Sea countries and accelerate the energy transition. These assumptions were defined in agreement with DESNZ. **Figure 2** below describes the three scenarios at a high level.

Figure 2: High level scenario development[14]

Scenario 1: Baseline scenario

DESNZ Known policy as of 2022, with sensitivities to reflect Net Zero Higher Demand scenarios

Key features:

Investment takes place as per current policy objectives to reach the UK's North Sea infrastructure targets in the four asset classes.

Scenarios 2: Holistic domestic scenario

Investment takes place under a holistic approach between UK developers, with coordination across the four infra-structure asset classes on a domestic level.

Key features:

- Co-ordinated grid approach within UK
- Co-ordinated consenting / planning within UK
- Energy "hubs"
- Better co-ordination amongst public bodies and regulators

Scenario 3: Holistic international scenario

Investment takes place under a holistic approach between UK developers and developers in neighbouring North Sea countries (NSC).

Key features:

- Co-ordinated grid approach in international waters
- Co-ordinated consenting and planning with non-UK projects
- Energy "hubs"
- Integration of UK and NSC on transmission and storage
- Compatible regulatory and market regimes

Source: Grant Thornton

For each scenario, discussed in detail below, each asset class is considered, including how it is used as well as its potential deployment.

Scenario 1 - baseline scenarios

Scenario 1 is the baseline scenario, which models the current state of play against which the value of additional coordination and cooperation has been evaluated. Specifically, it assesses how, based on current policy, a holistic development of offshore renewables and low carbon technologies in the North Sea can provide commercial and economic value to GB. Current policy in scenario 1 was considered in two ways: Known Policy and the Net Zero Higher scenario, both of which are from the DESNZ 2022 reference case.

a) Known Policy

The Known Policy scenario outlines what the electricity sector and underlying market conditions would look like if the Government made no further policy interventions beyond what has already been implemented, adopted or planned.

Section 4 defines these assumptions in further detail, giving the basis on which Known Policy is incorporated into the modelling approach. At a high level, the following can be considered as baseline across each of the energy asset types:

- **Offshore wind:** a continuation, but no change, of Contracts for Difference (CfD) for North Sea offshore wind projects and uncoordinated seabed leasing by the Crown Estate and Crown Estate Scotland, Connections of offshore wind to the network are through radial transmission connections via standard OFTO routes.
- **Interconnectors:** limited centralised planning with continuation of Cap & Floor regime through, with a point-to-point approach taken for assets connecting to GB and foreign countries. This includes limited deployment of MPIs in line with HMG ambitions.
- **CCUS:** deployment follows the CCUS business model targets through Track-1 and Track-2 and follows a linear growth between 2030 and 2050 to meet targets for 2030, 2035 and 2050 set out in DESNZ's CCUS Vision.[15] CO_2 storage is initially focussed within the GB market and coordination between the players in the value chain is limited to the cluster sequencing process.

[14] For the key features of scenario 2, it should be noted that DESNZ policy in 2024 does include elements of network coordination; networks are considered holistically, for example, the Holistic Network Design and Beyond 2030 National Blueprint.
[15] Carbon Capture, Usage and Storage (publishing.service.gov.uk)

- **Low Carbon Hydrogen:** planning and delivery is expected to follow hydrogen allocation rounds with deployment limited to land-based production which is split between blue and green hydrogen.[16]

As part of sensitivity analysis, the baseline scenario was extended to a more stretching case of higher demand for renewable electricity, which sets the likely outcome for investment. This outcome takes place as per current policy objectives which have been set to achieve Net Zero targets and is outlined below.

b) Net Zero Higher scenario

The Net Zero power sector scenarios were generated by DESNZ using the Dynamic Dispatch Model (DDM). These scenarios represent two technically feasible pathways for the decarbonisation of the power sector, which are defined as high and low demand profiles to capture possible outcomes.[17] Based on discussions with DESNZ, the Net Zero Higher Electrification scenario (hereinafter referred as Net Zero Higher) is used as the 'stretch' baseline for a sensitivity analysis. It consists of overall indicative electricity demand of around 765 TWh.[18] This is expected to be achieved through greater deployment and use of electric vehicles, more heat pumps or favourable economic growth that leads to higher electricity demand.

The use of the Net Zero Higher scenario is also consistent with industry modelling and reflects the 2050 goal under the updated Climate Change Act 2019. This sensitivity has been included to understand the benefits of holistic coordination and international cooperation in the form of system costs reductions, GHG emissions, consumer costs. Table 5 summarises the baseline scenarios.

Table 5: Baseline scenarios

Baselines	Description
Known policy	Outlines what the electricity sector and underlying market conditions would look like if the Government made no further policy interventions beyond what has already been implemented, adopted or planned.
Net Zero Higher	Based on UK TIMES[19] High Electrification scenario for the Net Zero strategy. Road transport nearly all electrified with higher overall traffic levels. Higher electrification of heat in homes and businesses.

Source: Net Zero and the Power Sector scenarios, DESNZ

Scenario 2 - Holistic domestic scenario

Scenario 2 focuses on a holistic reframing of strategic planning for offshore renewables and low carbon technology projects in the UK. Such an approach integrates renewable assets into a more cohesive and synergistic structure.

This would involve a number of stakeholders across each asset class, including developers, the Government, the Crown Estate and network operators. Such an undertaking would involve a harmonisation across these stakeholders and their operations. A holistic approach to coordination is expected to serve to lower regulatory barriers and reduce lead times for project development.

The step-change between scenario 1 and scenario 2, as shown in **Figure 3** below, captures the economic and commercial value which could arise from such an undertaking. This represents a shift

[16] Blue hydrogen is produced from natural gas with carbon capture and storage provision; green hydrogen is obtained from a renewable resource using green energy sources.
[17] The Dynamic Dispatch Model is GB level focused, and all power sector results herein are presented at a GB level.
[18] UK TIMES high demand scenario.
[19] UK TIMES | UCL ENERGY INSTITUTE MODELS - UCL – University College London

from a policy portfolio which regards individual technologies in isolation, to recognise the interconnected nature of energy systems.

Figure 3: Comparison of scenario 1 and scenario 2

Scenario 1: Baseline scenario

DESNZ Known Policy with sensitivities to reflect Net Zero Higher Demand scenarios

Key features:

Investment takes place as per current policy objectives to reach the UK's North Sea infrastructure targets in the four asset classes.

Scenarios 2: Holistic domestic scenario

Investment takes place under a holistic approach between UK developers, with coordination across the four infrastructure asset classes on a domestic level.

Key features:
- Co-ordinated grid approach within UK
- Co-ordinated consenting / planning within UK
- Energy "hubs"
- Better co-ordination amongst public bodies and regulators

Source: Grant Thornton

Four key features which arise in scenario 2 because of a more holistic approach to offshore renewable networks in the North Sea compared to current policy are:

i. **Creation of energy hubs**: A key feature of scenario 2 is the development of offshore energy hubs, which is expected to utilise wind energy resources in the North Sea to construct an artificial hub comprising a number of renewable energy inputs, such as offshore wind, hydrogen and solar power. These hubs are envisaged to have facilities to generate, store and distribute renewable energy, to supply power to GB. Renewable energy sources offshore have been assumed to be sited in collocated clusters of hydrogen and CCUS sites and take advantage of strong and consistent wind, making them more efficient. It should be noted that the technology required for the more significant offshore designs such as hub and spoke and energy islands is at an early stage. Direct Current circuit breakers suitable for use in the marine environment for example are not expected to be commercially ready until 2040 at the earliest.

ii. **Coordinated grid approach within GB**: A coordinated grid would mean building MPI's for offshore wind and other interconnectors[20] that would connect low carbon hydrogen production and CCUS facilities. In practice, this would mean development pathways being designed in such a way that renewables infrastructure deployment targets can be reached without duplication of network infrastructure. As a result, efficiencies and economies of scale could be maximised across asset classes. This would reduce cost and greenhouse gas emissions and rationalise space.

iii. **Coordinated consenting and planning within GB**: This envisages a streamlined, single window consenting mechanism for all the four infrastructures from all regulators and public bodies across GB. By involving a diverse group of stakeholders, relevant industry representatives are engaged in this work such that outcomes are mutually beneficial, and a collective understanding is reached to meet deployment targets.

iv. **Greater coordination amongst public bodies and regulators**: to underpin the above developments, it is implicit that public bodies such as departments and regulators would adopt a harmonised approach to organising the offshore grid and development of renewable energy and low carbon technologies in the North Sea. This is expected to include new and enhanced

[20] Interconnectors in this context are a type of Offshore Hybrid Asset (OHA). We have adopted the Ofgem definition of multipurpose interconnectors (MPIs) as offshore hybrid assets connected to an offshore generator in GB, which will conduct interconnection activities in GB and the connecting state as well as offshore transmission activities in GB (and optionally in the connecting state).

roles to bring together private stakeholders and public bodies and ensure that views are properly represented.

Rationale for scenario 2

Scenario 2 is framed based on evidence from markets, studies and reports that have stressed the need for coordination in the consenting of renewable infrastructure and low carbon technology projects in the North Sea. For example, the recent lack of engagement in CfD Allocation Round 5, and the early-stage development of allocation rounds for Hydrogen and CCUS, was recognised in the Review of Electricity Market Arrangements (REMA).

To this end, the Government and Regulators Electrification Group (GREG) has been formed with the aim to addressing barriers to success for decarbonising the oil and gas platforms with aim to facilitate CapEx investment, affordable electricity, regulatory streamlining and promoting infrastructure synergies to achieve the targets set in the North Sea Transition Deal which focuses on managing oil and gas shifting to clean growth.[21]

Furthermore, the Electricity Networks Commissioner (ENC) was commissioned by the Government to advise on how to reduce delivery time for GB transmission infrastructure.[22] Their report concludes that it is important to align objectives and deployment approaches across asset classes and highlights several key enablers. These include improving strategic planning, streamlining planning consent and expediting regulatory approval. Various workstreams are ongoing which action these suggestions- these include a consultation on revised energy National Policy Statements[23] to clarify and accelerate infrastructure deployment, and Ofgem's £20 billion Accelerating Strategic Transmission Investment decision to accelerate strategic infrastructure projects by 2030.

Scenario 3 - Holistic international scenario

Scenario 3 focuses on a holistic approach to offshore renewables deployment and low carbon technology projects between the GB and other North Sea countries. This would support the development of a cross-border offshore energy systems integration between GB and other North Sea countries and accelerate the energy transition. Additionally, this would generate opportunities and markets to GB which would otherwise be unavailable.

To achieve such outcomes would require coordination between various stakeholders and their respective counterparts in other North Sea countries to reach deployment goals across the four asset classes and reach Net Zero. Figure 4 below, shows the comparison between scenarios 2 and 3.

Figure 4: Comparison of scenario 2 and scenario 3

[21] North Sea Transition Deal (publishing.service.gov.uk)
[22] Electricity Networks Commissioner: companion report findings and recommendations (publishing.service.gov.uk)
[23] Planning for new energy infrastructure: revisions to National Policy Statements - GOV.UK (www.gov.uk)

Scenarios 2: Holistic domestic scenario

Investment takes place under a holistic approach between UK developers, with coordination across the four infrastructure asset classes on a domestic level.

Key features:
- Co-ordinated grid approach within UK
- Co-ordinated consenting / planning within UK
- Energy "hubs"
- Better co-ordination amongst public bodies and regulators

Scenario 3: Holistic international scenario

Investment takes place under a holistic approach between UK developers and developers in neighbouring North Sea countries.

Key features:
- Co-ordinated grid approach in international waters
- Co-ordinated consenting and planning with non-UK projects
- Energy "hubs"
- Integration of UK and NSC on transmission and storage
- Compatible regulatory and market regimes

Source: Grant Thornton

Five key features arise in scenario 3 from adopting a more holistic approach to international coordination among the North Sea countries. These are:

i. **Creation of energy hubs**: the creation of energy hubs would follow the same principles as that of scenario 2 but extend beyond GB borders to cross-border energy hubs with other North Sea countries.

ii. **Coordinated grid approach in international waters:** a coordinated grid across North Sea countries would collocate offshore renewable energy assets. In practice, this is expected to involve complementary spatial planning between countries. A complementary grid system where North Sea countries can mutually connect would be constructed under an agreed set of standards, which tracks across all asset types and countries.

iii. **Coordinated consenting and planning with non-GB projects**: this scenario envisages a project development process where timescales are aligned (thereby offering some flexibility in country-by-country planning mechanisms) and mitigation of barriers such as misalignment of regulatory frameworks. This is expected to ensure commercial viability and reduced lead times for all parties involved.

iv. **Integration of the GB and North Sea countries on transmission and storage**: coordinating a grid approach between GB and other North Sea countries would share transmission, distribution and storage infrastructure. This could take different forms but in principle it involves coupling of distinct energy assets such as interconnectors, wind power, hydrogen, and CCUS. This is expected to result in a cost-efficient system, with increased output or higher efficiency than its individual components. Some clear examples of systems integration opportunities are:

   - CO_2 transport through existing re-purposed gas pipelines and/ or storage of that CO_2 in depleted gas reservoirs;
   - Production of hydrogen on or around existing gas assets and/or transport of hydrogen through repurposed gas pipelines (including blending of hydrogen in the existing natural gas system); and
   - Electrification of ongoing oil and gas production to reduce emissions.[24]

v. Compatible regulatory and market regimes: scenario 3 would manage asymmetry in market frameworks which may inhibit the effectiveness of international collaboration. This would involve

[24] Source: Net Zero Technology Centre report: One North Sea - Cross-border collaboration in the North Sea energy transition

dialogue between Governments and other relevant stakeholders, as well as alignment on incentives and underlying domestic policy.

Rationale for scenario 3

Scenario 3 is based on evidence from studies and reports which emphasise that there is interest in integrated cross-border energy systems with hybrid[25] interconnectors between the countries in the North Sea. However, challenges remain such as uniform standards, clear definitions and aligned legal and regulatory frameworks.

To this end, European Network of Transmission System Operators for Electricity (ENTSO-E) do not anticipate significant growth in hybrid generation capacity before 2030. Between 2023 and 2030, they expect 3.4 GW of hybrid generation capacity to come online; this is expected to expand to 17.4GW by 2040.[26] Expansion is expected to be driven largely by existing projects and offshore renewable energy integration is expected to largely remain as radial connections.

3.3 Infrastructure-specific developments under each scenario

Four key offshore energy assets are within the scope of this report: (i) offshore wind, (ii) interconnectors, (iii) hydrogen, and (iv) carbon capture, use and storage (CCUS). Whilst each of the four key asset types are captured in the three scenarios above, this sub-section further expands on the development of these technologies under each scenario.

This approach assumes that the current gap in a holistic approach towards meeting climate targets within and outside of UK is addressed through better internal coordination and external cooperation with members of the NSEC on the various asset classes.

These configurations are not prescriptive but are instead a stylised representation of how the four infrastructures may develop in a holistic way. Therefore, there is flexibility in how these technologies could be harmonised under a holistic approach to realise economic and commercial benefits. These are considered further in Sections 5 and 7.

Offshore wind

Table 6 below shows how offshore wind could be expected to develop across the three scenarios, using a range of parameters throughout the development period.

Table 6: Offshore wind baseline, holistic domestic scenario and holistic international scenario

Scenarios	Description
Scenario 1: Baseline	*Incentives for investment* - CfD auctions support delivery of offshore wind in the North Sea consistent with long-term capacity forecasts. *Leasing* - Leasing rounds delivered by the Crown Estate and Crown Estate Scotland. *Network design* - Radial transmission connections via standard OFTO route. - Interconnectors have limited centralised planning having a point-to-point approach. - Limited use of MPIs.

[25] Hybrid systems “combine interconnection with the transmission of electricity generated by offshore windfarms and create direct links between power grids and windfarms” – source Ofgem
[26] ENTSO-E TYNDP 2024 Sea-Basin ONDP Report – Northern Seas Offshore Grids (windows.net)

Scenarios	Description
Scenario 2: Holistic domestic	*Incentives for investment* - CfD auctions support delivery of offshore wind in the North Sea consistent with long-term capacity forecasts. *Leasing* - Greater coordination between NESO, the Crown Estate and Crown Estate Scotland and accelerated consent process. *Network design* - Offshore grid is connected to MPIs. - Hub and spoke.
Scenario 3: Holistic international	*Incentives for investment* - Growth in incentives within CfD to incentivise greater "non price factors" – this could be extended to include international coordination between projects in areas such as port infrastructure and connection model. *Leasing* - International seabed leasing coordination to reconcile with international offshore wind and electricity transmission projects. *Network design* - Connection to offshore platforms in non-GB waters and/or direct cross-border trading. - Energy "hubs" incorporate GB and non-GB projects. - Coordinated planning with non-GB projects e.g. international bidding market for electricity. - Reconciliation with other technologies. - Coordination of market mechanisms.

Four key parameters were considered as the scenarios were constructed. These are:

i. **Incentives for investment:** it is assumed that the current CfD regime is expected to continue to move forward to ensure some degree of certainty for stakeholders. However, as the approach to operating offshore wind becomes increasingly holistic, these CfDs may begin to incorporate non-price factors into their valuation to ensure timely development of offshore wind and better support the supply chain industry that are currently facing issues due to lower margins. Depending on the factors included, this is expected to embed an integrated approach to network planning at the early stages of offshore wind development.

ii. **Leasing:** as a more holistic and integrated approach is adopted around network design, leasing and spatial planning is expected to take this into account. This would be at the domestic level in scenario 2, and across respective bodies in other North Sea countries in scenario 3. This would be done in a way that is increasingly compatible with each countries' domestic ambitions.

iii. **Planning:** planning rounds is expected to develop to accelerate rollout for collaborative projects between domestic and international stakeholders over the two scenarios. This potentially can ensure that offshore wind projects interlink to the holistic network design and projects are deployed in a timely manner to reach infrastructure targets.

iv. **Network design:** scenarios 2 and 3 are expected to enhance network design to integrate offshore wind, CCUS and hydrogen across energy hubs and multinational projects. Part of this involves a transition from radial point-to-point connections to MPIs resembling a hub-and-spoke concept with other North Sea countries.

Rationale for offshore wind development assumption in the scenarios:

Offshore wind is the more mature renewable energy technology compared to the other three technologies being considered in the scope of this report.[27] It is expected to play an important role as it feeds into the other technologies, primarily through hubs:

Interconnectors have been assumed to transmit electricity produced by offshore wind farms onshore and to other countries. This will help to balance electricity supply and demand across the North Sea, reinforcing security of supply.

CCUS and hydrogen facilities are assumed to utilise the power generated by offshore wind for carbon capture, storage and transport, and electrolysis respectively.

Across the UK, large-scale offshore wind developments are concentrated on the East coast of England and Scotland. Further inward investment including a new factory for foundations in Teesside, a new cable factory in Blyth and an expansion of Siemens Gamesa's Hull-based offshore wind turbine factory are also ongoing.

Interconnectors

Table 7 shows how interconnectors might be expected to develop across each of the three scenarios outlined above across a range of parameters with consideration for the broader network.

Table 7: Interconnectors scenario development

Scenarios	Description
Scenario 1: Baseline	*Incentives for investment* - Limited centralised planning - Projects treated in isolation *Leasing* - Cap & Floor regime *Network design* - Point-to-point assets connect GB to neighbouring markets - NESO GB Connection Reform project

[27] Hydrogen Production Delivery Roadmap (publishing.service.gov.uk)

Scenarios	Description
Scenario 2: Holistic domestic	*Planning* - Development of CSNP to better consider cumulative impacts from electricity network infrastructure, including economic and efficient outputs and delivery *Leasing* - Coordination across stakeholders to incorporate transmission network considerations throughout the seabed leasing process *Network design* - MPIs allow Offshore Wind (OSW) connections to offshore platform, CCUS and hydrogen sites - Energy hubs allow other NSIs - Onshore interconnectors built at higher speeds/volumes to accommodate offshore ambitions - Holistic Network Design to encourage offshore wind and interconnector projects to coordinate connections beyond radial approach
Scenario 3: Holistic international	*Planning* - International grid network planning *Leasing* - International seabed leasing coordination to reconcile with international interconnection and offshore projects *Network design* - MPIs allow OSW connections to offshore platform - Energy hubs allow other NSIs - Interconnectors built at higher speeds/volumes to accommodate offshore ambitions - Holistic Network Design to encourage offshore wind and interconnector projects to coordinate connections beyond radial approach

At present, GB's electricity market has 9.8 GW of electricity interconnector capacity across eleven interconnectors, connecting with France, the Netherlands, Belgium, Norway, Republic of Ireland, Denmark and Northern Ireland.[28]

Four key parameters which are considered as scenarios are constructed. These are:

i. **Incentives for developers:** over the development of a holistic approach to renewables infrastructure, developers are expected to see increased incentives to become involved in interconnector projects and enhance the capabilities of the UK in this space.
ii. **Leasing:** seabed leasing is expected to be coordinated by the Crown Estate and their international counterparts to ensure that interconnectors are properly placed to service all of the relevant countries and assets in the North Sea. This is expected to reconcile with a holistic network design overseen by the relevant forums and authorities in each country.
iii. **Planning:** interconnectors are expected to begin to treat projects as integrated, and link across countries and projects in accordance with an overarching network design. The development of interconnectors are assumed to consider the best-use of assets in order to achieve deployment

[28] What are electricity interconnectors? | National Grid Group

goals and provide the relevant stakeholders for these projects and related projects which make use of the interconnectors with a common understanding of the use of the interconnectors.

iv. **Network design:** interconnectors are expected to form a critical element of network design, bridging projects and energy hubs to reduce the overall impact of these projects by centralising to some degree. This effect has the potential to be amplified by incorporating multiple countries. However, this must be mutually agreed, and priority usage and cost-sharing was assumed to be consented as part of the scenario development. Using interconnectors which adhere to international standards, North Sea countries are expected to be able to connect to collaborative assets.

Rationale for infrastructure development assumption in the scenarios:

The Offshore Transmission Network Review (OTNR) considered how adopting a more strategic approach to offshore wind development, including how best to facilitate MPIs as part of a new asset class of Offshore Hybrid Assets (OHAs) which also includes Non-Standard Interconnectors (NSIs).[29] This workstream is being progressed by joint consultations between DESNZ and Ofgem on the Market Arrangement for MPIs and the Regulatory Framework for Offshore Hybrid Assets.

To ensure proper deployment at the required scale, there is a focus on improving the consenting process with an eye towards coordination. In February 2023, the Action Plan for Nationally Significant Infrastructure Projects (NSIP) was published. This has established measures to speed up the NSIP consenting process with emphasis on equity, resilience and quality.[30]

Furthermore, an emphasis on developing system compatible standards and terminology across projects is important to ensure that a common understanding of the role of interconnectors in domestic and international projects, including energy hubs, is properly established.

Hydrogen

Table 8 below shows how hydrogen could be expected to develop across each of the three scenarios outlined above across a range of parameters throughout the development period and with consideration for the broader network.

Table 8: Hydrogen scenario development

Scenarios	Description
Scenario 1: Baseline	*Planning* - Hydrogen allocation rounds (as part of hydrogen production delivery roadmap) *Network design* - Some hydrogen to power capacity connected to GB network *Market delivery* - Hydrogen business models followed; some CCUS enabled hydrogen production and some electrolytic hydrogen production using OSW and solar capacity

[29] Offshore Transmission Network Review: summary of outputs - GOV.UK (www.gov.uk)
[30] Nationally Significant Infrastructure: action plan for reforms to the planning process - GOV.UK (www.gov.uk)

Scenarios	Description
Scenario 2: Holistic domestic	*Planning* - Accelerated hydrogen allocation rounds - Established integration with OSW and CCUS *Energy "hubs"* - Increased hydrogen production offshore utilising energy "hubs" and direct OSW generation
Scenario 3: Holistic international	*Planning* - GB projects able to access adjacent electricity markets for hydrogen production - Complete integration of GB and North Sea Countries transmission and large-scale storage infrastructure *Energy "hubs"* - Multiple energy "hubs" connected to multiple countries and dynamically responding to changing demands, with surplus electricity used for hydrogen production *Market delivery* - Scope for trading market focused on exports

Four key parameters which were considered as scenarios are constructed are:

i. **Planning:** given the relatively nascent stage of development, development of hydrogen through these scenarios is expected to require strategic direction to be set in terms of the use case of hydrogen. This requires a refinement of hydrogen allocation rounds. As international projects come to the fore, the planning is expected to establish how UK and North Sea counterparts are able to integrate their transmission and storage infrastructure.

ii. **Energy hubs:** the role of hydrogen in siting at energy hubs and how North Sea countries are expected to be able to access the hub, in terms of market mechanisms and access rights. It also considers the way hydrogen electrolysers are located offshore, adjacent to each wind turbine. Scenario 3 assumes that hydrogen and renewable electricity are distributed across interconnected grids.

i. **Market delivery:** as an understanding of the role of hydrogen and project requirements are developed, it is expected that the business models underpinning deployment. In an international holistic grid design, this assumes consideration for export markets and establishment of trading rules between countries.

ii. **Network design:** a collective understanding of how hydrogen cab be integrated with a holistic network design at both domestic and international levels to serve respective markets.

Rationale for hydrogen development assumption in the scenarios:

The Hydrogen Production Delivery Roadmap (HPDR), published in December 2023, assesses the state of hydrogen deployment in the UK against the target of 10GW by 2030 in the two years since the UK Hydrogen Strategy was first published.[31] The HPDR expects to see increasingly larger electrolytic projects in locations which take advantage of renewable electricity generation sites.

Projects are developing in the UK on the East coast. Four projects are being developed in Yorkshire and the Humber, as well as one project in Suffolk. There are also three projects on the East coast of Scotland.[32] Hydrogen technologies are expected to help decarbonise energy-intensive industries such

[31] Hydrogen Production Delivery Roadmap (publishing.service.gov.uk)
[32] Hydrogen in the UK - Hydrogen UK (hydrogen-uk.org)

as steel (concentrated in locations such as Port Talbot and Scunthorpe), whilst supporting the transition from legacy sectors across potential sites.[33]

CCUS

Table 9 below shows how CCUS could be expected to develop across each of the three scenarios outlined above across a range of parameters throughout the development period and with consideration for the broader network. These categories are market delivery, customer access and transport.

Table 9: CCUS scenario development

Scenarios	Description
Scenario 1: Baseline	*Market delivery* - CCUS business models achieve targets through Track-1 and Track-2 expansion *Customer access* - Carbon storage facilities primarily servicing UK based CCUS projects. - Limited customer base *Transport* - Limited transport coordination
Scenario 2: Holistic domestic	*Customer access* - Increased access to customer base in GB market - Enhanced investment in large scale long duration electricity storage, including LODES program *Transport* - Increased coordination of transport of captured carbon and storage in North Sea facilities *Energy "hubs"* - Integrated production with hydrogen and OSW
Scenario 3: Holistic international	*Customer access* - Ability to access customers / storage facilities outside of GB waters *Transport* - Transport of non-GB captured carbon to GB storage facilities *Market delivery* - Scope for trading market focused on exports

Four key parameters which are considered as scenarios are constructed. These are:

i. **Energy hubs:** energy hubs are expected to begin to integrate CCUS with hydrogen using CCUS-enabled hydrogen as per Track-1 and Track-2 expansions to support rollout of current projects and enhance future developments. This assumes an agreed market arrangement to integrate the technologies to an agreed standard that are accessible by other North Sea countries in a trade arrangement.

[33] Clean_Growth_Gap_Community_Capital_WEB.pdf (energy-uk.org.uk)

ii. **Market delivery:** CCUS business models are expected to develop across these scenarios from domestic deployment underpinned by proper incentives and market mechanisms for procurement and delivery in the first instance to being established assets in the North Sea, with integration into international markets for cross-border CO_2 transport and storage with other North Sea countries.
iii. **Customer access:** in scenario 1 and 2, CCUS is focused on domestic delivery and enhancing capabilities to service the UK market using CCUS. This is expected to improve in scenario 3 to allow other non-UK markets in the North Sea to access CCUS capabilities generated by the UK.
iv. **Transport:** these scenarios are expected to capture an improvement in coordination between UK and non-UK projects to transport and store CO_2 across borders. This is assumed to be based upon an agreed sharing and transport mechanism which reconciles with respective market mechanisms.

Rationale for CCUS development assumption in the scenarios:

The Government has provided funding for a series of industrial clusters which are expected to deploy CCUS and hydrogen technologies across new and existing sites[34] which score highly in terms of economic deprivation.[35] As part of the development of these cluster plans, allocation has started with projects likely to use the infrastructure across industrial user groups and power stations.[36]

In the UK, areas in the Northeast such as County Durham and Sunderland have a high concentration of CCUS patents, a large concentration of carbon-intensive industries and a proximity to depleted oil and gas fields.[37] Tees Valley currently produces half of the commercially available hydrogen in the UK.[38] This makes the UK well-suited to develop industrial CCUS sites.

[34] Clean Growth Grand Challenge: Industrial Clusters Mission - infographic (publishing.service.gov.uk); Hydrogen Production Delivery Roadmap (publishing.service.gov.uk): there are four CCUS clusters being taken forward in development: HyNet in Northwest England and Wales, the East Coast Cluster including Teesside and the Humber, the Viking CCS in the Humber, and Acorn in Northeast Scotland.
[35] English indices of deprivation 2019 - GOV.UK (www.gov.uk); Scottish Index of Multiple Deprivation 2020 - gov.scot (www.gov.scot); Welsh Index of Multiple Deprivation | GOV.WALES
[36] The North Sea Transition Deal is progressing well, working across the industry, BEIS and other key stakeholders (nstauthority.co.uk)
[37] Growth, net zero and levelling up: three mutually-reinforcing objectives to encourage investment in the UK - Grantham Research Institute on climate change and the environment (lse.ac.uk)
[38] Clean_Growth_Gap_Community_Capital_WEB.pdf (energy-uk.org.uk)

4 Modelling approach

4.1 Introduction

The system and consumer cost savings were evaluated as “benefits” of the greater coordination with respect to both the Net Zero Higher and Known Policy baseline scenarios from DESNZ. For each scenario, the savings from both holistic domestic coordination and holistic international coordination were considered.

For each coordination scenario, the following were evaluated:

- The cost impacts arising through changes in power market outcomes. This includes changes in generation costs, network costs and capital costs, and the subsequent impact on wholesale prices and policy costs.
- Additional network cost savings through coordination of offshore networks. The evaluation of network costs in power market modelling assumes radial connections for offshore wind farms. There are additional savings from coordinating the deployment of offshore networks which are captured separately.
- Further CCUS and Hydrogen savings. Principally through greater coordination of network and storage infrastructure for captured carbon, including due to production of blue hydrogen. The savings due to greater utilisation of green hydrogen electrolysers offsetting natural gas use is captured in the power market modelling.

Aggregating these savings to produce overall system and consumer cost savings produces the results below, which are disaggregated and discussed in this section. This also includes the total carbon emissions reduction over the studied period.

Table 10: Summary of total benefits from a holistic domestic and international approach

	Holistic Domestic Coordination	Holistic International Coordination
	(£ billion 2025-50 NPV 2023, real)	
	Known Policy baseline	
System benefit	21.3	24.3
Consumer benefit	14.6	18.3
Total CO_2 reduction	37.1	46.3
	Net Zero Higher	
System benefit	15.6	11.6
Consumer benefit	5.8	12.3
Total CO_2 reduction	(1.9)	(0.4)

Source: Grant Thornton analysis

4.2 Energy systems modelling

LCP Delta's EnVision modelling framework, which stochastically simulates power markets and network utilisation across Western Europe, was used to assess the impact of greater coordination on system and consumers costs across the cooperation scenarios.

The economic benefits of the holistic domestic and holistic international scenarios compared to the baseline scenarios in terms of system costs and consumer costs. The holistic domestic scenario (scenario 2) encapsulates a more coordinated grid approach within Great Britain, with GB developers coordinating across the four North Sea asset classes. The holistic international scenario (scenario 3) involves a more coordinated international approach in development and investment across neighbouring North Sea countries.

Outputs from this modelling include impacts on GB wholesale prices, emissions, power generation, and system and consumer costs in the power sector. Cost outputs from the model use the framework agreed between DESNZ and LCP in 2015 and used by DESNZ in all power sector Value for Money and Impact Assessments.

4.3 Modelling Approach

The modelling inputs are based on the three scenarios and their underlaying assumptions presented in Section 3. The following sub-section summarises the three scenarios underpinning the outputs which are described in this section.

4.3.1 Scenario 1: baselines of Known Policy scenario with a sensitivity of the Net Zero Higher scenario

Scenario 1 is the baseline scenario, which models the current state of play against which the value of additional coordination and cooperation has been evaluated. This comprised the Known Policy scenario and Net Zero Higher scenario, summarised in Table 11 below. These scenarios were published as Annex O of the government's Energy and Emissions Projections[39].

Table 11: Summary of baseline scenario

Baseline scenarios	Description
Known Policy	Outlines what the electricity sector and underlying market conditions would look like if the Government made no further policy interventions beyond what has already been implemented, adopted or planned.
Net Zero Higher	Based on UK TIMES[40] High Electrification scenario for the Net Zero strategy. Road transport nearly all electrified with higher overall traffic levels. Higher electrification of heat in homes and businesses.

4.3.2 Scenario 2: holistic domestic scenario

Scenario 2 is the holistic domestic scenario, which focusses on a more integrated approach between developers in GB. A greater coordination in consenting and planning across all four asset types is expected. Public bodies and regulators are also expected to play a greater role, with increased coordination between themselves and developers. This more coordinated approach could facilitate the development of MPIs supporting energy islands.

39 Energy and emissions projections: 2021 to 2040 - GOV.UK (www.gov.uk)
40 UK TIMES | UCL ENERGY INSTITUTE MODELS - UCL – University College London

A holistic domestic scenario is expected to enable greater coordination in non-price factors, such as coordination on port infrastructure and connection models. A greater coordination between the National Energy System Operator (NESO) and the Crown Estate and Crown Estate Scotland is expected to consider network transmission in the leasing process, allowing for accelerated consenting for offshore wind to link to the grid, including via MPIs.

It is expected for the offshore grid to have a networked design for offshore projects, including connections to MPIs. These factors were reflected in the modelling of offshore wind through increased capacity and a reduction in network costs from avoided radial connections.

In the Net Zero Higher scenario, it is assumed that the pace of offshore wind deployment is not accelerated because the scenario is itself ambitious and the deployment profile is assumed to be a system-cost optimal given the pace of demand growth, so additional capacity may not be beneficial. In Known Policy, there are benefits to higher offshore wind deployment as shown in the modelling and therefore an increase in capacity was modelled in both scenario 2 and scenario 3.

Table 12: Comparison between scenario 2 and baseline scenarios with respect to offshore wind

Scenario	Capacity and deployment	Other changes
Net Zero Higher	No changes	Holistic Network Design is assumed to **reduce offshore network costs by 18%.**[41]
Known Policy	Greater coordination is assumed to accelerate deployment of North Sea offshore wind, **increasing capacity by 8%.**	

Scenario 2 sees the development of CSNP enabling a more integrated North Sea network that considers economic and efficiency impacts. For offshore wind development, leasing follows a more coordinated approach which can save time and cost. MPIs are constructed allowing connections of offshore energy projects in British waters with further speed and efficiency developments in their buildout.

Table 13: Comparison between scenario 2 and baseline scenarios with respect to interconnectors

Scenario	Capacity and deployment	Other changes
Net Zero Higher	No changes	Under each scenario, **MPIs are assumed to coordinate domestic offshore wind generation** with interconnectors (see results for specific MPI assumptions).
Known Policy		

Greater coordination of networks and storage for carbon, including from blue hydrogen production, is assumed to reduce the cost of meeting targets for CCUS deployment as set out in DESNZ's *CCUS Vision*[42].

[41] https://www.nationalgrideso.com/document/182936/download
[42] Carbon Capture, Usage and Storage (publishing.service.gov.uk)

Table 14: Comparison between scenario 2 and baseline scenarios with respect to CCUS

Scenario	Capacity and deployment	Other changes
Net Zero Higher	No changes	The cost of building CCUS storage infrastructure[43] is assumed to reduce by 6.5%[44] with greater coordination.
Known Policy		

There are significant uncertainties on the cost of CCUS networks, therefore a central view of a study of global CCUS storage costs across a range of storage archetypes was adopted. The study used to quantify potential coordination benefits is based on modelling of a specific case study in the Midwest USA, and therefore there are substantial limitations when applying these savings to offshore coordination in GB. Further research and analysis of the specific sites which could be coordinated and the cost to develop them in the North Sea would be needed to improve this estimation.

4.3.3 Scenario 3: holistic international scenario

Scenario 3, also known as the holistic international scenario, has many of the same developments as scenario 2 but with a greater emphasis on international cooperation. This means that projects in the North Sea can be shared with neighbouring countries. This is expected to manifest itself in a more interconnected North Sea grid, greater coordination in planning and consenting non-GB projects, and multiple energy islands connected to multi-purpose interconnectors in both GB and international waters.

This scenario is similar to scenario 2 for offshore wind, but with a greater acceleration of offshore wind capacity under Known Policy.

Table 15: Comparison between scenario 3 and baseline scenarios with respect to offshore wind

Scenario	Capacity and deployment	Other changes
Net Zero Higher	No changes	Holistic Network Design is assumed to **reduce offshore network costs by 18%.**[45]
Known Policy	Greater coordination is assumed to accelerate deployment of North Sea offshore wind, **increasing capacity by 10%.**	

Scenario 3 has similar benefit to scenario 2 for interconnectors. However, network planning is international with seabed leasing and networks being coordinated between countries. Offshore energy projects can connect to MPIs from foreign as well as GB waters. This extra level of coordination can help to reduce network costs as well as spreading costs between countries.

43 The world needs to capture, use, and store CO2 | McKinsey
44 Analysis of cost savings from networking pipelines in CCS infrastructure systems - ScienceDirect
45 https://www.nationalgrideso.com/document/182936/download

Table 16: Comparison between scenario 3 and baseline scenarios with respect to interconnectors

Scenario	Capacity and deployment	Other changes
Net Zero Higher	No changes	Under each scenario, **MPIs are assumed to coordinate domestic offshore wind generation** with interconnectors (see results for specific MPI assumptions)
Known Policy		

This scenario has consistent savings to scenario 2 for CCUS deployment.

Table 17: Comparison between scenario 3 and baseline scenarios with respect to CCUS

Scenario	Capacity and deployment	Other changes
Net Zero Higher	No changes	The cost of building CCUS storage infrastructure[46] is assumed to reduce by 6.5%[47] with greater coordination.
Known Policy		

4.3.4 Cost assumptions

The key outputs of the modelling are the changes in consumer and system costs between the factual scenarios with greater coordination and the counterfactual. The cost changes are modelled in most detail for GB, with indicative changes for foreign markets in the holistic international coordination scenario, scenario 3.

System costs represent the costs of building, operating and maintaining the power system and are split into components shown in Table 18.

Table 18: Definition of system cost components

Component	Definition
Generation Costs	Fuel and variable operating costs (VOM) costs of plants associated with meeting electricity demand hour to hour, i.e. wholesale market dispatch.
Carbon Cost	Carbon costs based on carbon emissions priced at DESNZ's central appraisal carbon price[48]. The carbon cost can be split into two parts, carbon costs at the market price (carbon price plants pay) and unpriced carbon costs (additional carbon costs valued at appraisal value).
Capex Costs	Capital costs include pre-development, construction and infrastructure costs (all £/kW) for building plants. For system cost, this is cost of financing these investments, so are spread over the economic lifetime of the plant based on the assumed hurdle rate for the technology.

[46] The world needs to capture, use, and store CO2 | McKinsey
[47] Analysis of cost savings from networking pipelines in CCS infrastructure systems - ScienceDirect
[48] Valuation of greenhouse gas emissions: for policy appraisal and evaluation - GOV.UK (www.gov.uk)

Component	Definition
Fixed Opex Costs	Fixed operating costs of plants, any operating costs that do not vary with output, and represented in £/kW terms.
Network Costs	Cost of maintaining, reinforcing and extending the transmission network, including the costs of managing constraints. Note that distribution network costs are not included as these would need to be modelled separately.
Interconnection Costs	Costs associated with building, maintain and operating interconnectors. Costs are a 50:50 split between imports priced at the domestic market price and exports priced at the foreign market price.
Hydrogen production	Changes in utilisation of electrolysers are expected to affect the volume of green hydrogen produced. This green hydrogen is assumed to be a substitute for natural gas in other sectors. The benefits of hydrogen production are quantified using the fuel and carbon appraisal value of alternative natural gas.

Alongside these components, the changes in emissions between the factual scenarios and the counterfactual are presented as outputs.

The impact on consumer costs is all the costs that are passed on to consumer bills. For the evaluation in this project, changes in the components of consumer cost shown in Table 19 were considered.

Table 19: Definition of consumer cost components

Component	Definition
Generation Costs	Fuel and variable operating costs (VOM) costs of plants associated with meeting electricity demand hour to hour, i.e. wholesale market dispatch.
Carbon Cost	Carbon costs based on carbon emissions priced at DESNZ's central appraisal carbon price[49]. The carbon cost can be split into two parts, carbon costs at the market price (carbon price plants pay) and unpriced carbon costs (additional carbon costs valued at appraisal value).

Note: The cost of managing locational constraints and energy imbalances through the balancing mechanism are not considered in this evaluation.

Network costs associated with GB offshore wind are expected to be reduced in scenario 2 and 3 because of coordination with MPIs, removing most of the cost of the radial connection between the wind farm and the onshore transmission network. While this is quantified as a system cost saving, it is uncertain how this saving may pass through to consumers.

Network charges for offshore networks are currently charged through the OFTO regime. The offshore network and substation costs components of OFTO charges are separate from TNUoS charges and the costs are covered entirely by offshore generators. Therefore, the full reduction in offshore network costs do not directly reduce network costs for consumers. The 2024-25 Final TNUoS Tariffs[50] indicate that total OFTO revenue ("$OFTO_t$") is expected to be £880 million and the revenue from offshore generators ("*O*") is £693 million, which implies that 21% of the cost reductions would be seen by consumers as reductions in their demand residual.

[49] Valuation of greenhouse gas emissions: for policy appraisal and evaluation - GOV.UK (www.gov.uk)
[50] 2024-25 Final TNUoS Tariffs Report [Published] (nationalgrideso.com)

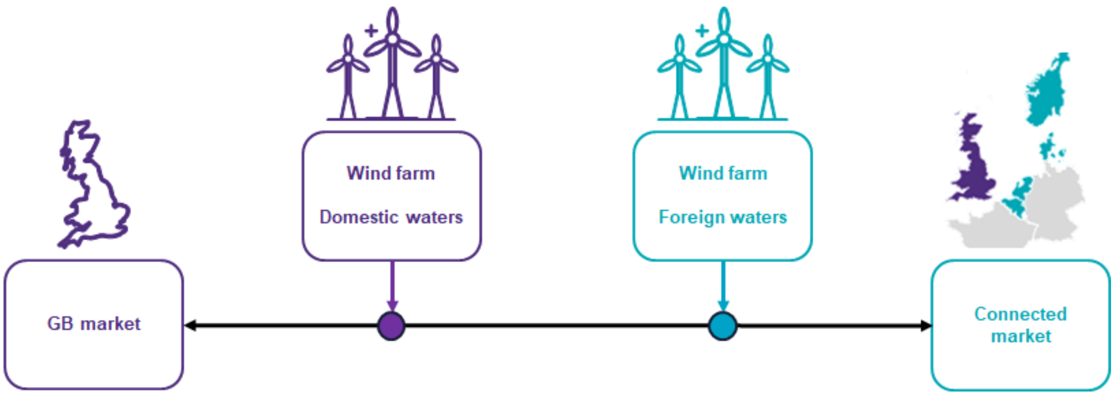
The remaining reduction in network costs may still pass through as a reduction in consumer bills, depending on what portion of the network costs the offshore wind farm retains and what savings are passed on to the interconnector. The savings retained by the wind farm could transfer into a reduction in the strike price required by the wind farm and lower policy costs. Alternatively, savings passed on to the interconnector developer may be reflected in a more favourable Cap and Floor agreement from the perspective of consumers, but the likelihood of these constraints biting within the modelling was not quantified. The approach has been to quantify the scale of the potential consumer cost saving if all savings are passed through to consumers and not consider how they may be shared between wind farm and interconnector developers.

4.3.5 Multipurpose interconnection configuration

Ofgem defines multipurpose interconnectors (MPIs) as offshore hybrid assets (OHA) connected to an offshore generator in GB, which will conduct interconnection activities in GB and the connecting state as well as offshore transmission activities in GB (and optionally in the connecting state).

Deploying multipurpose interconnectors is modelled as assuming that a wind farm and an interconnector share the same connection to a market. Figure 5 below shows the setup assumed in the modelling.

Figure 5: Modelled configuration of multi-purpose interconnection



The exact physical configuration of these assets to achieve these aims is not important to the modelling – what is important is the interactions between the generators using the MPI as offshore transmission and the flows between markets.

The diagram above illustrates how this could be configured, with an interconnector between two markets which is shared in each market by a local wind farm.

No offshore bidding zone were assumed, and that the offshore wind farms participate directly in their local market.

For modelling purposes, where interconnector flows are discussed, it assumes the flow between the two markets, which is the flow over the (possibly theoretical) central portion of the cable. For example, the connected market may have 200MW of generation flowing towards GB from onshore plus 300MW to GB from the connected foreign wind farm. This would be an import to GB of 500MW. If the connected domestic wind farm were also generating at 100MW meaning that the total flow onshore to GB on the cable is 600MW, this additional 100MW would not be an import and would instead be classed as domestic generation.

Impact of multipurpose interconnectors on flows

The generation of a wind farm connected to an MPI interacts with import flows into its home market. For example, in the configuration above with each of the domestic wind farm and the interconnector sized at 1,000MW and no foreign waters wind farm, if the wind farm is generating 600MW then potential imports are limited to 400MW because of flow limits on the interconnector.

Interconnector flows to the foreign market (exports) are not affected by a wind farm in GB waters. In the same example above, the interconnector can export at a full 1,000MW of which 600MW could be from the wind farm. In this case, the potential to export is not changed and in periods where GB exports to the foreign market, the generation mix in the foreign market is also not changed compared to a counterfactual without a wind farm connected to the MPI in GB waters.

The impact of a foreign water wind farm on the MPI is symmetrical to the discussion above – it affects imports into the connected market but does not affect exports to GB.

When both wind farms are connected, flows over the interconnector into each market are only restricted by wind generation on the MPI from the wind farm in that market's waters. Note that this may be different if offshore bidding zones modelled instead.

Impact of multipurpose interconnectors on the wind farm's home market

Moving to using an MPI (without changing the overall capacity mix) would increase the costs of meeting demand in the wind farm's home market through domestic generation and imports. This is because the interconnector is strictly less flexible than in the counterfactual, in which the interconnector and offshore wind farm are realised but not coordinated.

For example, in periods where the interconnector would have imported more had the wind farm not been generating, the interconnector imports must be replaced with either more expensive domestic generation or other imports.

In the system costs outputs, this is expected to be seen as an increase in generation and balancing costs, which outweigh the savings on interconnector costs. The corresponding system cost saving for the home market could be a reduction in network costs, as the radial connection of the home market wind farm could be avoided.

The coordination of network assets is expected to have a positive impact in the form of system cost savings for the home market when the network cost saving exceeds the increase in the costs of meeting demand and balancing the system the latter caused by reduced interconnector flexibility.

Consumer costs in the domestic market are expected to increase because the market price of power is usually higher in periods where the interconnector's imports are restricted. This can be partially offset by a reduction in policy costs from CfDs, as reference prices for those contracts are set to increase in those periods under the current design.

The potential reduction in network costs from the avoided radial wind farm connection may also pass through as a reduction in consumer bills, depending on how the cost reductions are incurred and by which parties as discussed above.

Impact of multipurpose interconnectors on the wind farm's foreign market

The MPIs are expected to reduce exports from the wind farm's foreign market, which reduces revenue from interconnector exports for that market. In the system cost assessment, this can be seen as an increase in net interconnector costs (imports costs minus export revenue). This system cost increase can be partially offset by a reduction in generation and balancing costs in that market because they no longer generate as much power to export, but the net effect can translate into an increase in system costs.

There are no network benefits for the wind farm's foreign market because the wind farm's radial network cost is not assumed to be incurred by that market.

Consumer costs in the foreign market are expected to decrease due to lower wholesale prices because they no longer export as much in some periods, lowering the marginal cost of generation in those periods. Depending on the policy support mechanisms in the foreign market, this saving may be partially offset by an increase in policy costs.

As before, there may be positive implications for the level of policy support required by the interconnector, but this analysis does not attempt to quantify these.

Moving to using an MPI should increase the costs of meeting demand in the wind farm's home market. This is because the interconnector is strictly less flexible than in the counterfactual.

Relationship with typical interconnector behaviour

The cost of changing interconnection flows due to MPIs will depend on the conditions under which the wind farm's domestic market imports power.

The most impactful instances where interconnectors flows change are expected to be those in which the marginal cost of generation in one market is set by renewable generation, and the other is set by thermal generation. This is because the cost of replacing imports are expected to be high and the exporting country is likely to lose high revenue for low-cost generation.

If the home market is more heavily driven by wind generation than the foreign market, then it is assumed to import during low wind generation periods and the restriction of flows on the MPI are expected to be limited. This leads to a small change in interconnector and generation costs when the offshore wind farm and interconnector are connected as an MPI.

If the home market is less driven by wind generation than the foreign market, then it may see periods of higher wind generation where it looks to import because market prices are lower abroad. These periods could be as described above, where the importing market has a market price set by thermal generation.

In this scenario, the interruption caused by the MPI is significant in terms of restricting the flow, because the domestic wind farm is generating at a high level at a time when the interconnector would import. Additionally, the cost of that interruption could be significant due to market price differences.

It can be concluded that placing a domestic wind farm on a multipurpose interconnector can be more impactful to interconnector flows, and hence system costs, if the home market has a relatively low level of wind generation compared to the foreign market and the domestic connection is capacity constrained.

In the Net Zero Higher scenario, GB is likely to have a high penetration of wind generation compared to the connected countries. This could translate to wind farms connected to MPIs in foreign waters having significant impacts on GB generation and interconnector costs.

In the Known Policy scenario, this balance is likely to shift due to lower wind deployment in GB and constant assumptions on the foreign market capacity mix.

4.3.6 Modelling outputs: scenario 2 against Net Zero Higher baseline

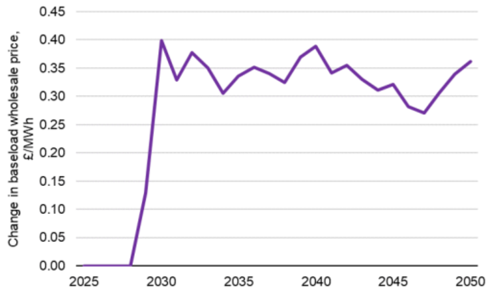
In scenario 2, there are three MPIs are expected to be connected in 2030 as shown in Table 20 below. While the interconnector and associated offshore wind farms (OSW) exist in the baseline, they are not coordinated.

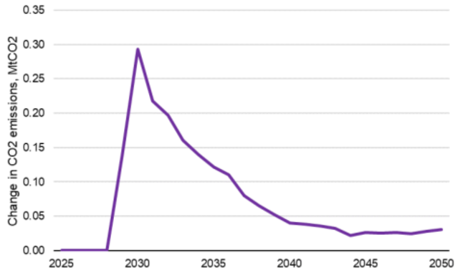
Table 20: Multipurpose interconnector assumptions in scenario 2

Connected country	Online year	Interconnector size	OSW size
Belgium	2030	1,400 MW	GB: 1,400 MW Foreign: None
Norway	2030	1,800 MW	GB: 1,500 MW Foreign: None
Norway	2030	1400 MW	GB: 1,300 MW Foreign: None

The reduced import capacity in scenario 2 relative to the baseline of the interconnector increases dependence on GB generators. This increases the wholesale price in GB and raises carbon emissions. In connected markets, there would be a reduction in wholesale prices and lower carbon emissions. However, the effects as shown in **Figure 6** are relatively small as interconnector imports are restricted during periods of high renewable generation with lower cost, lower emission generation at the margin.

Figure 6: Wholesale price and carbon emissions changes in scenario 2 against Net Zero Higher baseline

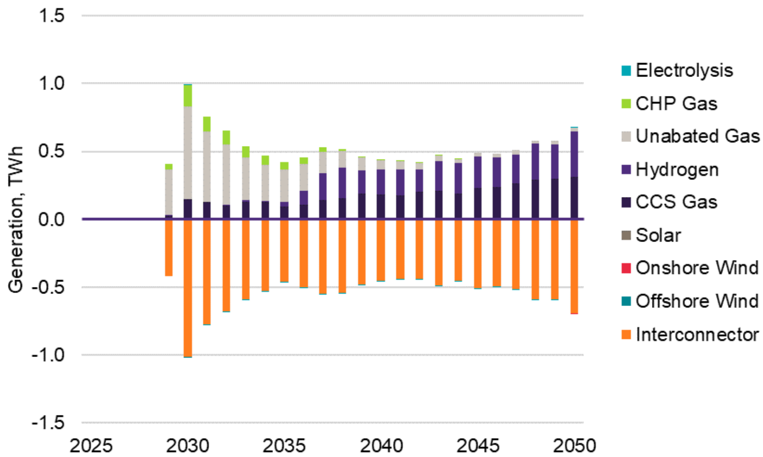




The resulting changes in generation are shown below in Figure 7. In early years, reduced interconnector imports are replaced by unabated gas generation. In later years, as GB shifts towards net export to interconnected markets, there are fewer periods in which imports are reduced relative to the baseline. As the thermal fleet decarbonises, the reduction in imports is met by additional hydrogen and CCS Gas generation.

However, compared to the results discussed below for scenario 3 under Net Zero Higher, the change in generation mix is limited because GB is a heavy exporter to foreign markets in this scenario.

Figure 7: Generation mix changes in scenario 2 against Net Zero Higher baseline

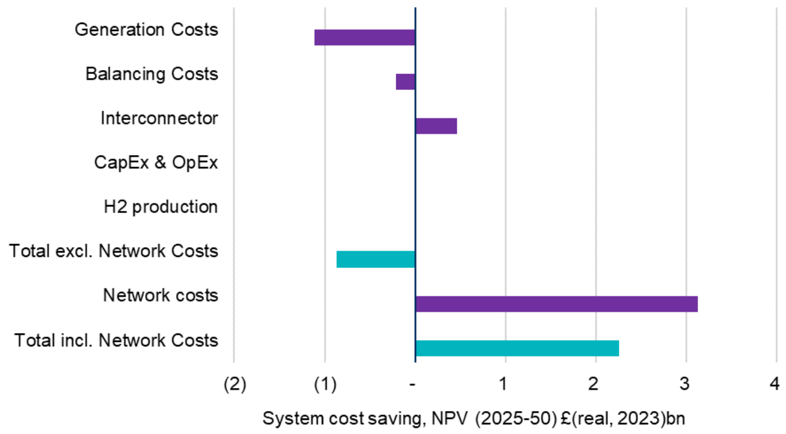


Note: technologies with minor generation changes across all presented results have not been shown.

This translates into higher system costs of generation, as expected and shown in Figure 8 below. Reduced interconnector import flexibility leads to higher generation and balancing costs, and a smaller saving on interconnector costs.

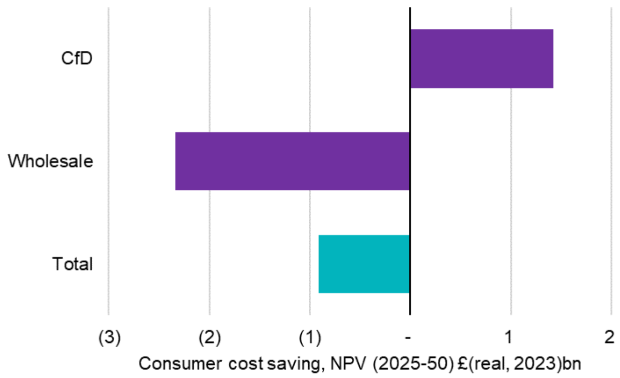
However, the network cost saving of not building 5.2GW of radial connections for the MPI-associated domestic offshore wind farms outweighs this greater generation cost. The net benefit between 2025 and 2050 is £2.3 billion (NPV 2023, real).

Figure 8: Modelled system net benefit in scenario 2 against Net Zero Higher baseline



Increasing wholesale prices can potentially lead to higher consumer bills, offset by a reduction in CfD support payments. These elements are shown in Figure 9 below and show a net cost to consumers of £0.9 billion (NPV 2025-2050, real 2023).

Figure 9: Modelled consumer cost impacts in scenario 2 against Net Zero Higher baseline



There are additional system and consumer benefits under scenario 2 which have not been captured within the power market modelling above and are discussed below.

Wider network cost savings from greater coordination

Analysis from National Grid ESO (now NESO) as part of their analysis of coordinated offshore networks estimated that such networks could reduce expenditure on capex and opex for development of the offshore transmission grid in GB by 18%[51].

Using the estimate of offshore network costs per MW of offshore capacity as described above, it is estimated that the total offshore network cost of Net Zero Higher is approximately £45.2 billion (NPV real, 2023). This implies that greater coordination could lead to saving of approximately £8.3 billion (NPV real, 2023).

This is independent of, but similar to, the estimate produced by NG ESO (now NESO)[3] of a £6.6 billion (NPV real, 2020) saving, adjusted for the DESNZ Net Zero Higher scenario and inflation.

Pass through of network cost savings to consumers

As discussed above, the reduction in network costs may also pass through to consumers depending on how these cost reductions are realised.

[51] https://www.nationalgrideso.com/document/182936/download

If, at a high level and without certainty on distributional effects, it is assumed that network savings are shared equally between producers and consumers, then consumers benefit overall by £4.1 billion (NPV real, 2023). This accounts for both the cost reductions from network coordination and reduced offshore wind connections from MPIs.

CCUS and hydrogen system benefits

The benefits of greater utilisation of electrolysers are accounted for in the power market modelling above. The remaining hydrogen benefit is realised through lower CCUS costs for blue hydrogen production, which can be considered alongside wider CCUS cost reductions.

There is significant uncertainty on the cost of CCUS networks, and less clear quantification on the possible benefits of coordination. Through literature research, an approach was developed which estimates the benefits for the DESNZ market scenarios.

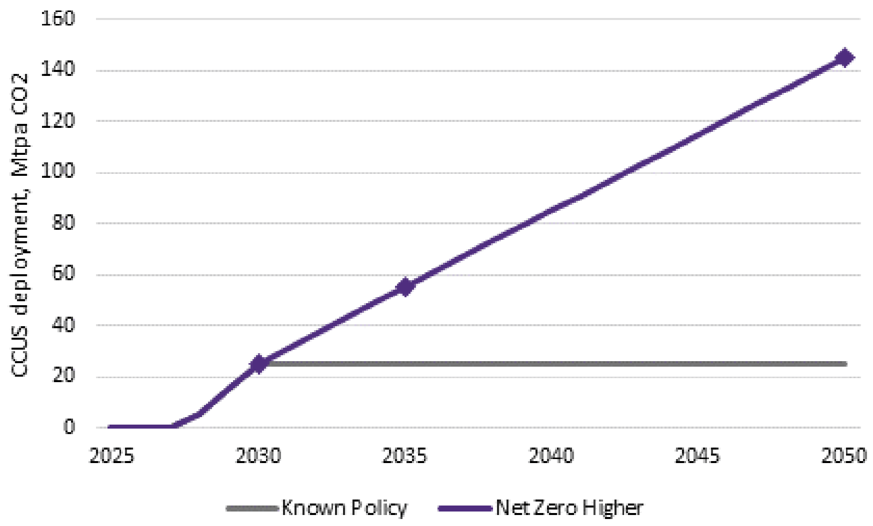
The published *CCUS Vision*[52] from DESNZ established Government's ambition for annual CCUS utilisation in 2030, 2035 and 2050. These ambitions were:

- **2030**: 20-30 Mtpa CO_2
- **2035**: At least 50 Mtpa CO_2
- **2050**: 90-170 Mtpa CO_2

Figure 10 below outlines the trajectories for annual CO_2 capture assumed in the Net Zero Higher scenario. A constant rate of growth between 2030 and 2050 was considered which meets the stated targets.

In the Known Policy scenario, analysed with the same approach later in this report, no growth in CCUS deployment beyond 2030 was assumed.

Figure 10: Assumed annual CO_2 capture, Known Policy and Net Zero Higher baselines



The cost of deploying a CCUS network is uncertain and there is no published data from DESNZ on CCUS costs due to commercial sensitivity of project developers.

A published report from McKinsey[53] looked at the cost of CCUS across a range of international hubs to create a cost curve for carbon capture. This study estimated that the majority of hubs could capture carbon below $100/t$CO_2$. Using the estimate of carbon capture costs at £80/tCO_2 the annual cost of carbon capture in GB was estimated between 2025 and 2050 to be £78.1 billion (NPV 2023, real).

[52] Carbon Capture, Usage and Storage (publishing.service.gov.uk)
[53] The world needs to capture, use, and store CO2 | McKinsey

Note that this approach is imperfect, because the cost profile of building networks and storage will be weighted towards early capital expenditure and then a profile of operational costs. Therefore, the approach taken is an approximation of the potential costs.

Further literature research, including case studies of CCUS clusters[54], has suggested that the cost reductions from coordination are approximately 6.5%. Applying this saving to the forecast network costs for CCUS suggests a benefit between 2025 and 2050 of approximately £5.1 billion (NPV 2023, real).

As for electricity network benefits, it is unclear how this benefit may pass through to consumers. As above, it was assumed that 50% of this benefit is realised as a cost reduction for consumers.

Total system and consumer benefits

Adding these additional benefits to the modelled benefits outlined above, the total system and consumer benefits of scenario 2 relative to the baseline under Net Zero Higher were estimated.

Table 21: Benefits of under scenario 2 with Net Zero Higher baseline

Component	System benefit	Consumer benefit
	2025-50 NPV £billion (2023 real)	2025-50 NPV £billion (2023 real)
Power market costs	2.3	(0.9)
Electricity network costs	8.3	4.1
CCUS and H2 costs	5.1	2.5
Net benefit	**15.6**	**5.8**

4.3.7 Modelling outputs: scenario 3 against Net Zero Higher baseline

In scenario 3, there are four MPIs connected in 2030. The additional MPI is an exemplar project to the Netherlands which was modelled as a conventional interconnector in other scenarios. As is the case for scenario 2, while the interconnector and associated wind farms exist in the baseline, they are not coordinated.

Note that in this commentary scenario 3 compared against the baseline, rather than scenario 2. Therefore, results showing differences include the effects of the change under scenario 2 and the additional changes under scenario 3. In some cases, these changes may offset one another.

Table 22: Multipurpose interconnector assumption in scenario 3

Connected country	Online year	Interconnector size	OSW size
Belgium	2030	1,500 MW	GB: 1,400 MW Foreign: None
Norway	2030	1,800 MW	GB: 1,500 MW Foreign: None
Norway	2030	1,400 MW	GB: 1,300 MW Foreign: None

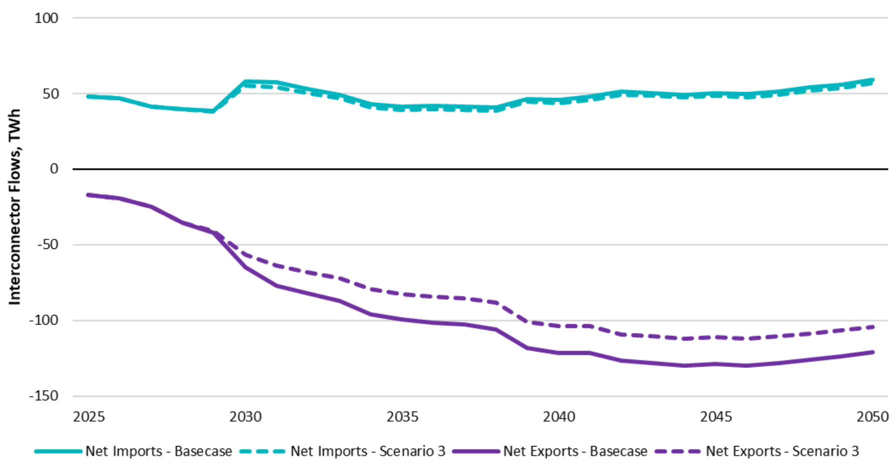
[54] Analysis of cost savings from networking pipelines in CCS infrastructure systems - ScienceDirect

Connected country	Online year	Interconnector size	OSW size
The Netherlands	2031	Domestic connection and interconnector: 1,800 MW Foreign connection: 2,000 MW	GB: None Foreign: 2,000 MW

Exports over the interconnectors are significantly affected by foreign waters wind farms connected to interconnectors. As discussed above, this is because GB has a higher deployment of wind generation and therefore exports during periods of high wind generation, which are correlated with reduced interconnector export availability. Interconnector export availability is reduced because generation from foreign wind farms connected to interconnectors results in congestion on the line and reduces the capacity for the foreign market to receive imports.

Figure 11 shows the change in total import and export. As seen for scenario 2, there is a limited impact on imports. However, there are substantial reductions in exports.

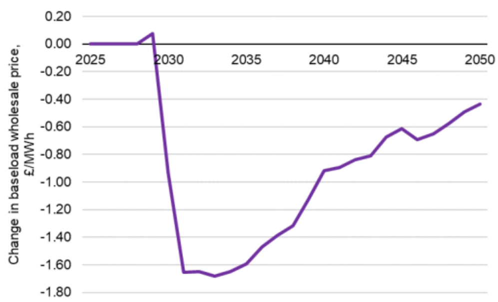
Figure 11: Total interconnector import and export in scenario 3 against Net Zero Higher baseline



Reduced interconnector exports reduce market prices in GB due to lower competition. This outweighs the effects of the reduced interconnector imports which raised prices in scenario 2. This also translates into lower domestic carbon emissions in periods when carbon intensive generation would have been exported. Both impacts are seen in Figure 12. In the foreign market, the opposite effects of higher emissions and market prices were observed.

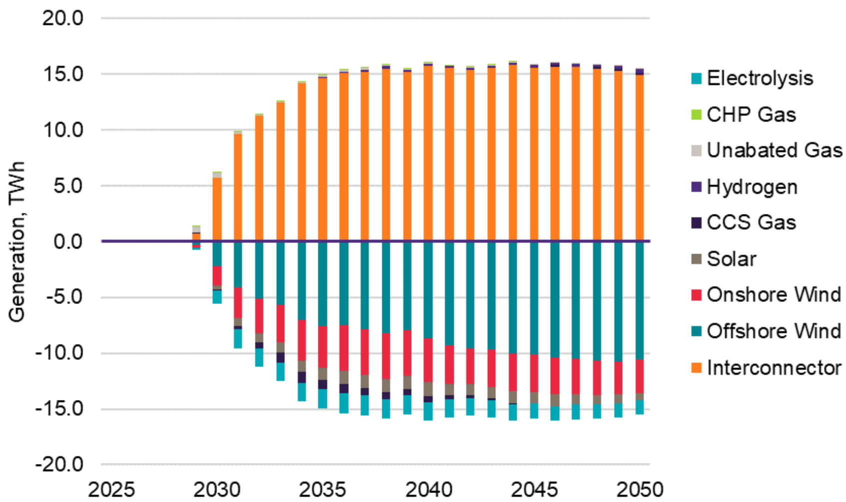
While emissions reductions are expected on one side of the interconnector (in this case GB) and increases on the other, the net effect is likely to be an increase in overall emissions. This is because reduced availability of interconnector capacity leads to less efficient dispatch of generation, which is likely to lead to higher emissions, because higher cost generation typically has higher emissions.

Figure 12: Wholesale price and carbon emissions changes in scenario 3 against Net Zero Higher baseline



The resulting changes in generation are shown below in Figure 13. Reduced interconnector exports of excess renewable generation lead to reductions in offshore wind generation and increases in the utilisation of electrolysers.

Figure 13: Generation mix changes in scenario 3 against Net Zero Higher baseline



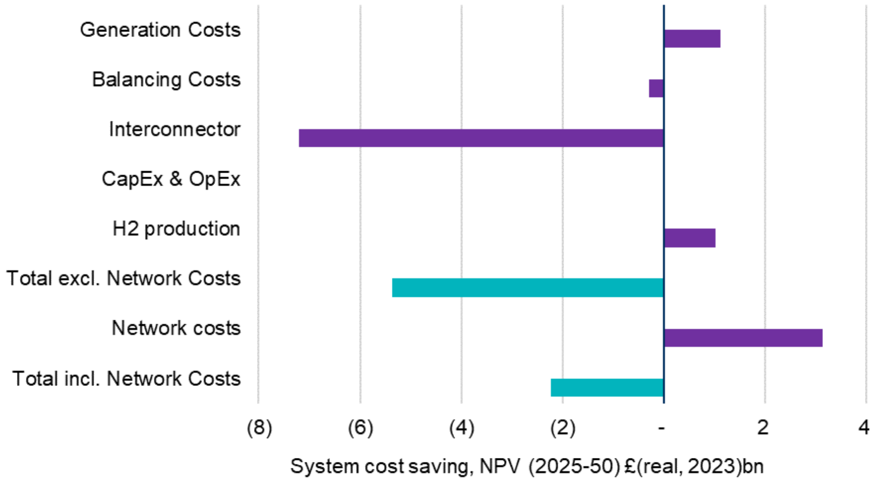
This results in lower system costs of domestic generation. However, most of the generation which has been reduced is low-cost renewable generation which has negligible system cost of generation.

There is likely to be a more significant loss of system benefit from interconnector exports sold at higher foreign market prices, displacing higher system cost generation in the foreign market. The system costs of interconnectors are valued at the net receipts from interconnector exports minus imports. For example, producing more power to allow greater exports can potentially increase domestic generation costs, but can be outweighed by benefits from the associated exports.

There is some additional benefit from the increased utilisation of electrolysers. The higher utilisation allows for more displacement of natural gas in other sectors, the fuel and carbon benefits of which are captured as a “Hydrogen production” benefit in Figure 14 below.

There are no additional network cost savings for GB on top of those calculated for scenario 2, as the network cost savings are benefits for foreign markets.

Figure 14: Modelled system cost impacts in scenario 3 against Net Zero Higher baseline



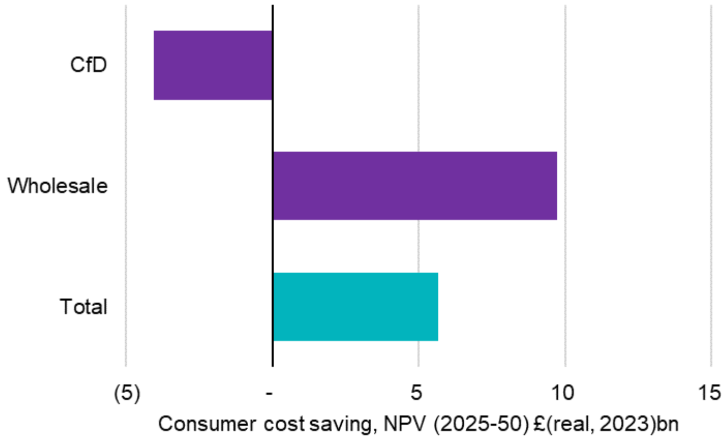
The overall system cost impact of scenario 3 compared to the baseline is an increase in system costs of £2.2 billion (NPV 2025-50, real 2023).

In this scenario, GB is a significant exporter of power and realises benefits from exporting over interconnectors to neighbouring markets. While it achieves network cost savings from domestic wind farms on MPIs, these are outweighed by restrictions on interconnector exports.

In the Known Policy scenario, with lower renewable deployment, it was observed that there is a net benefit to GB from coordination when the balance of interconnector flows is less heavily weighted towards export.

As shown in Figure 15, the lower wholesale costs are partially offset by higher policy costs due to lower renewable capture prices under CfDs. The resulting consumer cost saving is £5.7 billion (NPV real, 2023).

Figure 15: Modelled consumer cost impacts in scenario 3 against Net Zero Higher baseline



Total system and consumer benefits

The additional modelled benefits are consistent with those for scenario 2 and are summarised below:

Table 23: Benefits in scenario 3 under Net Zero Higher baseline

Component	System benefit	Consumer benefit
	2025-50 NPV £billion (2023 real)	2025-50 NPV £billion (2023 real)
Power market costs	(1.8)	5.7
Electricity network costs	8.3	4.1
CCUS and H2 costs	5.1	2.6
Net benefit	**11.6**	**12.3**

4.3.8 Modelling outputs: scenario 2 against Known Policy baseline

In scenario 2, there are three MPIs connected in 2030. While the interconnector and associated wind farms exist in the baseline, they are not coordinated.

Table 24: Multipurpose interconnector assumption in scenario 2

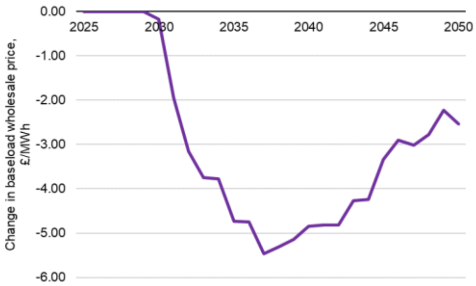
Connected country	Online year	Interconnector size	OSW size
Belgium	2030	1,400 MW	GB: 1,400 MW Foreign: None
Norway	2030	1,800 MW	GB: 1,500 MW Foreign: None
Norway	2030	1400 MW	GB: 1,300 MW Foreign: None

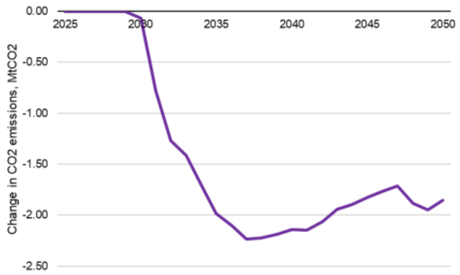
In the Known Policy scenario, domestic coordination allows for an increase of North Sea offshore wind capacity of 8%. This translates into an increase of around 2GW of total offshore wind capacity between 2030 and 2050 under assumptions provided by DESNZ.

As for Net Zero Higher, the interaction between MPIs and the associated offshore wind should lead to higher generation costs and emissions, all else being equal. However, it was assumed that greater coordination leads to higher offshore wind deployment in the Known Policy scenario. Since Known Policy is a higher emissions scenario which is not compliant with Net Zero in 2050, additional offshore wind is expected to have significant positive impacts on system and consumer costs.

Figure 16 below shows the impact on wholesale prices and carbon emissions, both of which decrease substantially with additional delivery of offshore wind capacity. This is because, in the baseline, offshore wind capacity stalls after 2030 and the cost of the additional carbon emissions grows substantially. Whereas coordination in the Net Zero Higher scenario raised wholesale prices by below £0.50/MWh, in Known Policy the domestic coordination scenario reduces wholesale price by more than £2/MWh beyond 2030, peaking at £5/MWh.

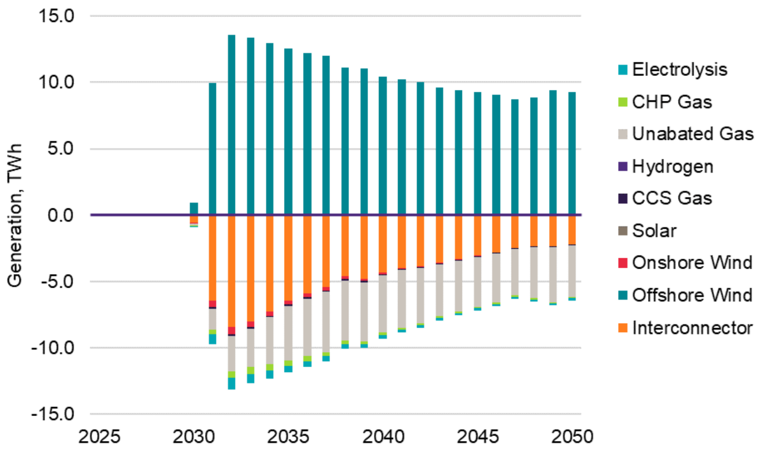
Figure 16: Wholesale price and carbon emissions changes in scenario 2 against Known Policy baseline





The resulting changes in generation are shown below in Figure 17. The primary drivers of change in the generation mix are higher offshore wind generation, offset by lower unabated gas generation and interconnectors imports (due both to lower GB prices and MPI import restrictions).

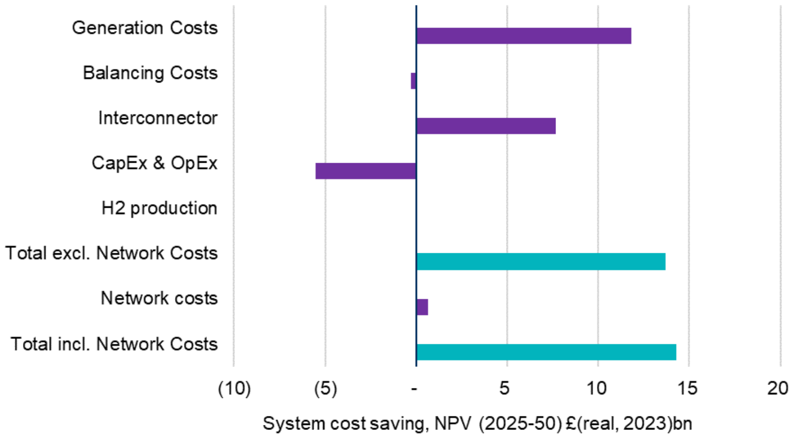
Figure 17: Generation mix changes in scenario 2 against Known Policy baseline



This translates into substantial system costs savings from generation – particularly driven by reductions in carbon emissions priced at the social cost of carbon – as shown in Figure 18. There are savings both on generation costs and interconnector costs. Note that balancing costs increase marginally, due to higher wind generation leading to larger balancing actions.

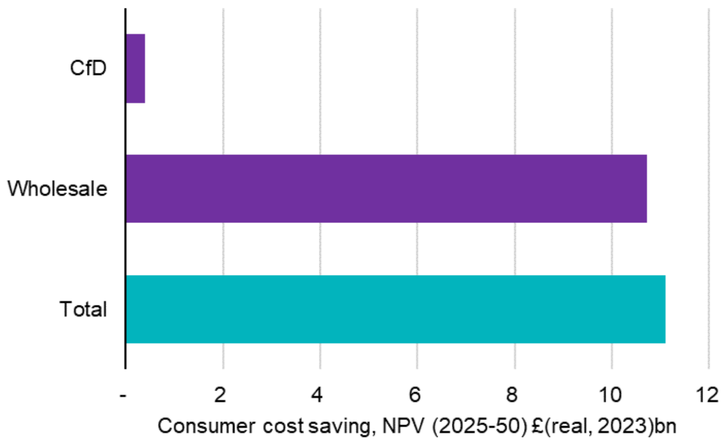
As for Net Zero Higher, there are substantial network costs savings from greater coordination. However, these are marginally outweighed by the network costs of the additional offshore wind capacity, leading to a small additional network cost. These additional generators who were not built in the baseline also incur additional capex and opex which reduce the benefit of scenario 2 relative to the baseline. Overall, the benefit between 2025 and 2050 is £14.3 billion (NPV 2023, real). In addition, since the work by the ESO in 2020, equipment costs and lead times for electrical equipment used both onshore and offshore have risen substantially. This means that the cost of ‘meshing’ networks has risen, reducing the opportunity for savings.

Figure 18: Modelled system cost impacts, Known Policy, scenario 2 against baseline



The significant reductions in the wholesale price leads to savings for consumers, offset partially by higher CfD payments to a greater volume of CfD supported capacity. Figure 19 shows that the net benefit to consumers is £11.1 billion (NPV real, 2023).

Figure 19: Modelled consumer cost impacts, Known Policy, scenario 2 against baseline



Wider network cost savings from greater coordination

As for Net Zero Higher, a wider network cost savings from domestic coordination is expected which were approximated under the same methodology.

The total offshore network cost in Known Policy was estimated to be £30.8 billion (NPV real, 2023) in scenario 2, before accounting for the 18% reduction in offshore network costs from greater coordination. Note that the additional network cost from greater offshore wind capacity is accounted for in the modelled benefits above.

Therefore, the additional benefit of greater coordination is estimated to be £5.3 billion (NPV real, 2023).

Pass through of network cost savings to consumers

As discussed above, the reduction in network costs may also pass through to consumers depending on how these cost reductions are realised.

If, at a high level and without certainty on distributional effects, it was assumed that network savings are shared equally between producers and consumers, then consumers benefit overall by £2.6 billion (NPV real, 2023). This accounts for each of the cost reduction from network coordination, increased offshore wind connections and network cost savings from MPIs.

CCUS and hydrogen system benefits

Following the same approach as for Net Zero Higher Electrification, but assuming no growth in CCUS deployment beyond 2030, the total cost of CCUS deployment between 2025 and 2050 is estimated to be £26.1 billion (NPV 2023, real). Assuming a consistent 6.5% reduction in costs, this leads to a system cost benefit between 2025 and 2050 of £1.7 billion (NPV 2023, real).

The methodology for producing the cost estimates and associated savings is consistent with that for Net Zero Higher, but assuming a lower build out profile as shown in Figure 10. Note that under both Net Zero Higher and Known Policy, additional CCUS deployment was not assumed due to greater coordination.

Total system and consumer benefits

Adding these additional benefits to the modelled benefits outlined above, total system and consumer benefits of scenario 2 relative to the baseline under Known Policy was estimated.

Table 25: Benefits in scenario 2 under Known Policy baseline

Component	System benefit	Consumer benefit
	2025-50 NPV £billion (2023 real)	2025-50 NPV £billion (2023 real)
Power market costs	14.3	11.1
Electricity network costs	5.3	2.6
CCUS and H2 costs	1.7	0.8
Net benefit	**21.3**	**14.6**

4.3.9 Modelling outputs: scenario 3 against Known Policy baseline

In scenario 3, there are four MPIs connected in 2030. As is the case for scenario 2, while the interconnector and associated wind farms exist in the baseline, they are not coordinated.

Note that in this commentary scenario 3 against the baseline is compared, rather than scenario 2. Therefore, results showing differences include the effects of the change under scenario 2 and the additional changes under scenario 3. In some cases, these changes may offset one another.

Table 26: Assumptions of MPIs and capacities in scenario 3

Connected country	Online year	Interconnector size	OSW size
Belgium	2030	1,500 MW	GB: 1,400 MW Foreign: None
Norway	2030	1,800 MW	GB: 1,500 MW Foreign: None
Norway	2030	1,400 MW	GB: 1,300 MW Foreign: None

Connected country	Online year	Interconnector size	OSW size
The Netherlands	2031	Domestic connection and interconnector: 1,800 MW Foreign connection: 2,000 MW	GB: None Foreign: 2,000 MW

In the Known Policy scenario, international coordination allows for an increase of North Sea offshore wind capacity of 10%. This translates into an increase of around 3GW of total offshore wind capacity between 2030 and 2050 under assumptions provided by DESNZ.

Unlike the Net Zero Higher scenario, GB is not a heavy exporter of generation to neighbouring markets due to lower renewable ambition.

Figure 20 shows the change in total import and export. Unlike Net Zero Higher, there are changes to imports but smaller changes to exports than under Net Zero Higher. The cost of reduced imports in scenario 2 was outweighed by the wider benefit of greater wind deployment. In scenario 3, there is expected to be limited impacts on system costs from reduced exports.

Figure 20: Total interconnector import and export in scenario 3 against Known Policy baseline

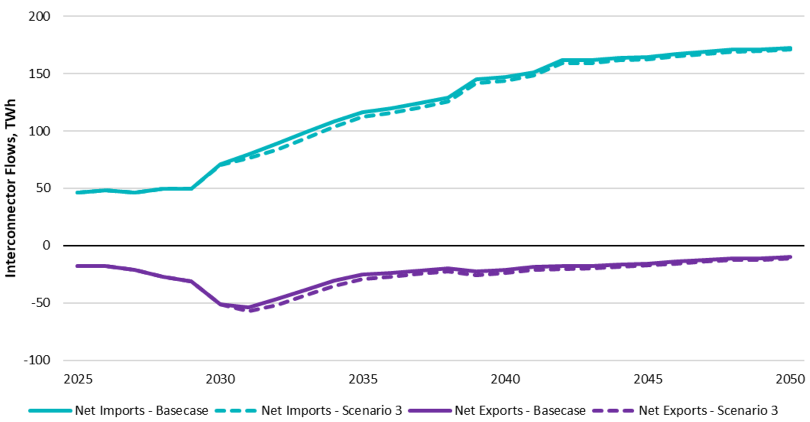
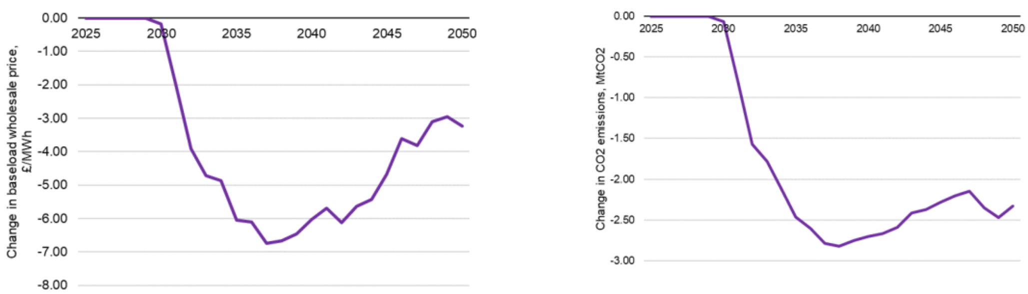


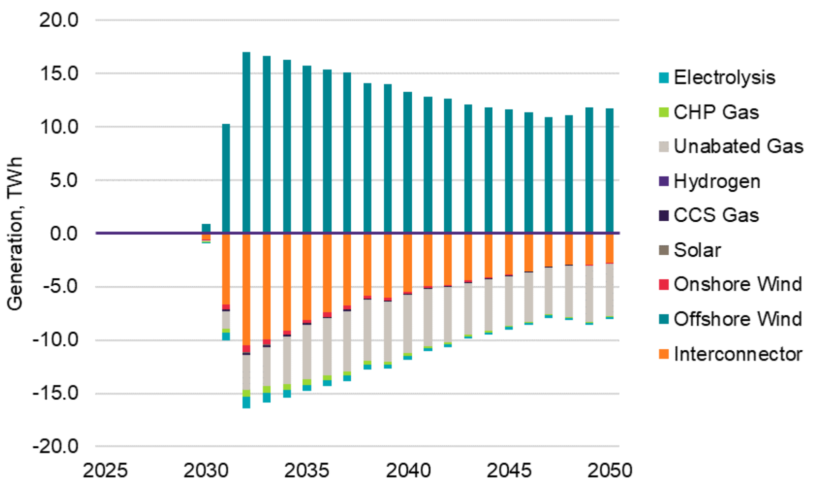
Figure 21 shows the impact on wholesale prices and carbon emissions relative to the baseline. As seen for scenario 2, there are substantial reductions in both, due to higher offshore wind deployment.

Figure 21: Wholesale price and carbon emissions changes in scenario 3 against Known Policy baseline



The resulting changes in generation are shown below in Figure 22. As for scenario 2, there are increases in offshore wind generation reducing GB's net imports and offsetting domestic thermal generation.

Figure 22: Generation mix changes in scenario 3 against Known Policy baseline

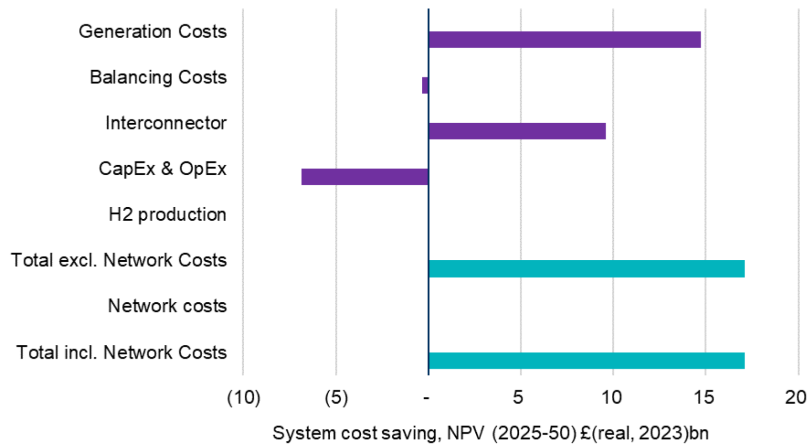


Note: technologies with minor generation changes across all presented results have not been shown.

There are no additional network cost savings for GB on top of those calculated for scenario 2, as the network cost savings are savings for foreign markets.

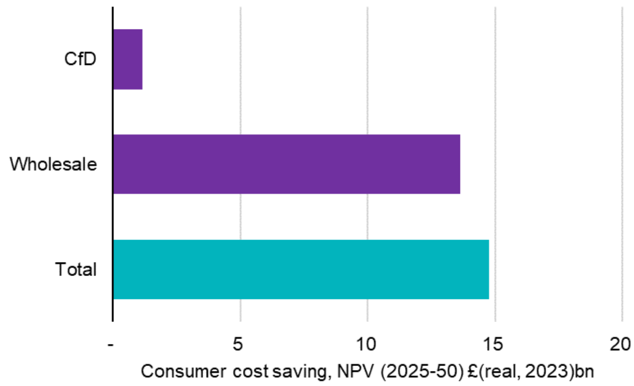
Figure 23 illustrates the overall system cost savings of scenario 3 compared to the baseline. The overall system cost saving is £17.1 billion (NPV real, 2023).

Figure 23:Modelled system cost impacts, Known Policy, scenario 3 against baseline



Lower market prices in GB lead to consumer cost savings as shown in Figure 24. The lower wholesale costs are partially offset by higher policy costs due to lower renewable capture prices under CfDs. The resulting consumer benefit is £14.8 billion (NPV real, 2023).

Figure 24: Modelled consumer cost impacts in scenario 3 against Known Policy baseline



Total system and consumer benefits

The additional benefits which have not been captured in the modelling are consistent with those for scenario 2 and are summarised below:

Table 27: Benefits of a holistic international approach under Known Policy baseline

Component	System benefit	Consumer benefit
	2025-50 NPV £billion (2023 real)	2025-50 NPV £billion (2023 real)
Power market costs	17.1	14.8
Electricity network costs	5.3	2.7
CCUS and H2 costs	1.7	0.8
Net benefit	**24.1**	**18.3**

5 Impact Analysis

5.1 Introduction

This section explores the potential economic benefits that could arise from more holistic coordination of UK's offshore renewables and through greater international cooperation by looking at fourteen critical success factors. These are grouped under seven key themes: Economic, Environment, Social, Spatial Geography, Regulation, Policy, and Technology, which were selected in conjunction with DESNZ.

A mix of qualitative and quantitative methods were used to assess the outcomes for each critical success factor. Some have been examined based on direct outputs from the systems modelling discussed in Section 4 and others have been examined through a qualitative assessment and a review of relevant literature.

5.2 Economic

5.2.1 System and consumer costs

Increased coordination at the domestic level (scenario 2) or cooperation at international level (scenario 3) is expected to make renewable energy generation cheaper while simultaneously increasing deployment capacity across all the four infrastructure types. This would translate into reduced system costs and would potentially lead to a reduction in energy bills. The modelling results showed reductions in system and consumer costs under the various scenarios. These are presented in detail in Section 4.

However, there is likely to be added complexities because of the need to have collaborative investments across multiple countries, each with their own regulatory frameworks, technical standards and grid codes. Consequently, costs would potentially be higher. System operators and other infrastructure organisations may need to navigate this complexity to ensure seamless integration of energy from offshore projects into the grid whilst maintaining system reliability and stability.

5.2.2 Job creation

The methodology utilised in the Energy Innovation Needs Assessment (EINA) reports was adapted to estimate gross jobs generated under the different scenarios for offshore wind, CCUS and hydrogen. While investments in interconnectors are expected to raise demand for construction jobs, they are not long-term jobs. Specific information on operation and maintenance job metrics on interconnectors were not readily available as for the above three energy assets and therefore could not be estimated with sufficient accuracy in this analysis.

The system cost savings are expected to be influenced by the jobs created to support the development of these technologies. With greater efficiency, there is the potential for higher labour productivity, which could mean fewer direct jobs.

While there are currently no studies that directly estimate the number of jobs that might arise from more coordination and greater international cooperation, there is evidence that an increase in the deployment of each of the technologies lead to jobs being created to support these sectors.

The Offshore Wind Industry Council forecasts that by 2030 there could be around 104,401 jobs in offshore wind in GB to deliver the current pipeline of 50GW, including 5GW of floating offshore wind[55]. In the case of hydrogen, analysis suggests the sector could support over 20,000 jobs by 2030 across hydrogen production, transport and storage value chains for domestic and export markets[56]. By 2050, in

[55] OWIC Offshore Wind Skills Intelligence Report - March 2022
[56] https://opergy.co.uk/hydrogen-sector-faces-challenges-to-build-up-workforce/

a high hydrogen deployment scenario, the hydrogen economy could potentially support up to 100,000 jobs[57]. The CCUS Net Zero Investment Roadmap estimates that 50,000 jobs could be supported by 2030 through the deployment of 4-5 CCUS clusters with an aim to capture 20-30 $MtCO_2$ per year[58].

The transmission grid is essential to the efficient use of the individual low carbon technologies. The Winser report estimates that if the development of transmission grid is committed to and necessary investments are made, 50,000 to 130,000 additional jobs could be supported across the country.[59] The jobs are expected to be both short-term (e.g., in the construction phase) and long-term (e.g., in areas such as operations and maintenance).

The methodology utilised in the EINA reports was adapted to estimate gross jobs generated under the different scenarios. Based on the deployment of offshore wind and low carbon hydrogen projects along with CCUS production capacity and the assumptions on capital expenditure and operations and maintenance costs used in the scenario modelling, were used to estimate the expected turnover per year from each of these infrastructure assets. Based on the infrastructure-specific EINA reports, assumptions on the level of turnover expected to be captured by the UK were made. This turnover was used to estimate jobs required in a given year using the appropriate job multiplier from the Input-Output tables published by the Office of the National Statistics (ONS).

Known Policy as baseline

Under the Known Policy, deployment is lower across all three technologies compared to Net Zero Higher. Up to 60,500 jobs was estimated to be generated by 2030 across the three technologies – Offshore Wind (Fixed and Floating), CCUS projects and Hydrogen energy generation. In the long run, up to 42,100 jobs was estimated to be generated by 2050 across these three technologies. Job generation potential reduces in the long term as deployment reduces from 2030, especially for Offshore wind.

Under scenario 2, with more domestic co-ordination, more structured planning and potentially quicker processing of projects, there is a potential for reduction in system costs thus decreasing capex costs for these projects. There is an assumed reduction of 18% system costs for Offshore Wind and 6.5% reduction in system costs for CCUS technologies whilst also expecting an increase in Offshore Wind capacity by 8%. Hence, up to 51,000 jobs was estimated to be generated by 2030, under scenario 2 across these three technologies. In the long run, around 35,800 jobs was estimated to be available across these technologies by 2050.

Under scenario 3, there is a similar system costs reduction as observed under scenario 3 but there is an assumed increase in Offshore Wind capacity by 10%. Therefore, it was estimated that up to 51,000 jobs could be supported by 2030 and in the long run up to 35,800 jobs to be supported by 2050 across the three technologies.

The analysis captures direct jobs and there is likely to be a substantial number of indirect and induced jobs in the baseline. Indirect jobs include roles in the relevant supply chains. Induced roles include jobs that are created due to increased employment in the local economy, which has a multiplier effect on local businesses. This is particularly true for CCUS and hydrogen which operates in regional clusters and are expected to positively impact the local economy due to increased demand for local goods and services from workers.

[57] Hydrogen Sector Development Action Plan (publishing.service.gov.uk)
[58] CCUS Net Zero Investment Roadmap (publishing.service.gov.uk)
[59] Electricity Networks Commissioner: companion report findings and recommendations (publishing.service.gov.uk)

Table 28: Job estimates under the Known Policy scenario

	2030	2050
Baseline	60,500	42,100
Scenario 2	51,000	35,800
Scenario 3	51,000	35,800

Net Zero Higher as baseline

There is a higher job generation potential under the Net Zero Higher scenario. Up to 66,400 jobs was estimated to be supported by 2030 across the three technologies – Offshore Wind (Fixed and Floating), CCUS projects and Hydrogen energy generation. In the longer run, around 134,900 jobs was estimated to be supported by 2050 across these three technologies.

Under scenario 2, with more domestic co-ordination, more structured planning and potentially quicker processing of projects, there is a potential for reduction in system costs thus decreasing capex for these projects. There is an assumed reduction of 18% in system costs for Offshore Wind and 6.5% reduction in system costs for CCUS technologies whilst also expecting an increase in Offshore wind capacity by 8%. Therefore around 56,300 jobs were estimated to be generated by 2030, under scenario 2 across these three technologies. In the long run, around 115,800 jobs were estimated to be available across these technologies by 2050.

Under scenario 3, there is a similar system costs reduction as observed under scenario 3, but there is an assumed increase in Offshore Wind capacity by 10%. Therefore, it was estimated that around 56,400 jobs could be generated by 2030 across these three technologies. In the long run, around 115,900 jobs were estimated to be available across these technologies by 2050. While the number of jobs supported is higher under the baseline (Net Zero Higher), it must be noted that these are estimations based on expected deployment and currently there are many barriers to such rapid deployment thus adding a higher level of uncertainty over such high job creation potential.

However, under scenario 2 and 3, while job numbers might be slightly lower, there is more certainty around the possibility of job creation as many stakeholders are expected to be working in co-ordination to achieve increased deployment of renewable energy resulting in more efficient use of capital and labour resources.

As in the known policy as baseline scenario, there is potential additional indirect and induced jobs as a result of the jobs supported by the three technologies in the Net Zero Higher as baseline scenario.

Table 29: Job estimates under the Net Zero Higher scenario

	2030	2050
Baseline	66,400	134,900
Scenario 2	56,300	115,800
Scenario 3	56,400	115,900

Limitations of the Methodology

This methodology estimates gross jobs that may be supported from domestic production and does not include jobs created from the exporting potential across these three technologies. Under scenario 2, there is expected to be a higher potential for exports thus allowing for increased job creation as compared to the baseline. This analysis also pertains only to the direct jobs made available and doesn't include any indirect or induced jobs that may be generated in the wider economy.

Construction is one of the areas that is expected to benefit from a boost in job creation. Under scenario 1 there would be a greater need for new infrastructure because of the reliance on point-to-point connectors over MPIs and a need for separate clusters in contrast to an integrated energy system. As such there may be more jobs in construction in the baseline than under the other two scenarios. For instance, as cooperation increases, infrastructure planning might become more comprehensive and efficient thus reducing construction demand. This is likely to result in fewer construction jobs. Therefore, whilst additional jobs may be created under these scenarios, they could be offset by jobs lost due to decarbonisation of other sectors in the UK economy.

The analysis provides estimates of labour demand under the scenarios, rather than labour supply. Many of the jobs created across the three technologies are likely to be in highly skilled occupations such as mechanical engineering, electrical engineering, high integrity welding, and environmental consenting. High demand for workers in these occupations across the energy sector and wider economy may limit the ability to fill jobs with the Offshore Wind, CCUS, and Hydrogen sectors. This presents both a challenge and an opportunity to encourage workers from the Oil and Gas sectors who may have transferable skills into green jobs in Offshore Wind, CCUS, and Hydrogen.

Under scenarios 2 and 3, job demand decreases compared to the baseline however, there is expected to be greater efficiency, hence, more energy production is possible with lesser labour. Additionally, job demand in the baseline scenario might be higher but there is no guarantee of adequate and skilled labour supply to fill these jobs. Thus, under scenarios 2 and 3, there is a higher likelihood of jobs being filled owing to comparatively lesser job demand.

Furthermore, the analysis does not make any assumptions on future innovation or technological progress within these sectors. Innovation could increase labour productivity in the future, therefore necessitating less workers under the same scenario.

5.2.3 Gross Value Added (GVA)

The estimates on the jobs created, were used to estimate the gross value added to the economy. The estimates were complemented with the various studies and reports that assessed the potential GVA from increased deployment of specific renewable energy-generating infrastructure.

For example, according to a report by the Offshore Wind Industry Council (OWIC) and the Offshore Wind Growth Partnership (OWGP)[60], growing the UK's supply chain for offshore wind represents a £92 billion opportunity to boost the UK's economy by 2040, For CCUS, studies suggest that GVA peaks during the construction phase and CCUS projects could add up to £1,733 million of GVA annually during that phase from 2024 to 2031. Estimates for hydrogen are roughly half that. According to the UK Hydrogen strategy, the UK's ambition of 5GW low-carbon hydrogen production capacity could add up to £900 million in GVA by 2030. Additionally, under the High Hydrogen scenario, £13 billion of GVA could be generated from the UK hydrogen economy by 2050[61].

Adapting the methodology from the EINA reports to estimate GVA, the above job estimates were used and the appropriate GVA per worker was applied from two sources of the ONS– the Environmental Goods and Services sector database and the productivity data by industry and region to provide a range of potential GVA that can be added to the economy under these scenarios.

60 https://www.owic.org.uk/news/offshore-wind-supply-chain-has-%C2%A392-billion-potential-for-uk-economy-by-2040
61 https://www.gov.uk/government/publications/uk-hydrogen-strategy/uk-hydrogen-strategy-accessible-html-version#fnref:9

Known Policy as baseline

It was estimated that under the baseline of Known Policy, these three technologies could add approximately £6.63 to £36.47 billion in 2030 and around £4.61 billion to £25.15 billion in 2050. Under scenario 2, keeping the assumptions similar to those used for the job estimation, it was estimated that the three assets could add approximately £6.64 to £36.51 billion in 2030 and around £4.62 to £25.18 billion in 2050. Under scenario 3, there is a slightly higher GVA added to the economy annually. In 2030, these three technologies could add around £6.66 to £36.58 billion while in 2050, the GVA generated is around £4.63 to £25.24 billion.

These estimations are subject to change as the productivity of workers in the renewable energy sector increases. There is a higher potential for productivity increase under scenarios 2 & 3, thus increasing the GVA potential under the methodology. Additionally, there is a marginal difference between the GVA generating potential under scenarios 2 and 3 as the changes expected to take place in scenario 2 and 3 are policy-specific and might not always translate into increased deployment across the three infrastructure technologies.

Table 30: GVA (low-high) estimates under the Known Policy baseline

	2030 (£ billion)	2050 (£ billion)
Baseline	6.63 - 36.47	4.61 - 25.15
Scenario 2	6.64 - 36.51	4.62 - 25.18
Scenario 3	6.66 - 36.58	4.63 - 25.24

Net Zero Higher as baseline

Given the higher job generation potential under the Net Zero Higher scenario, under the methodology, GVA added to the economy is also higher. It was estimated that under the baseline of Net Zero Higher , these three technologies could add approximately £7.28 to £38.39 billion in 2030 and approximately £14.78 to £67.77 billion in 2050. Under scenario 2, keeping the assumptions similar to those used for the job estimation, it was estimated that these three technologies could add approximately £7.32 to £38.65 billion in 2030 and around £14.81 to £67.96 billion in 2050. Under scenario 3, there is a slightly higher GVA added to the economy annually. In 2030, these three technologies could add around £7.33 to £38.71 billion while in 2050, the GVA generated is around £14.82 to £68.01 billion.

Table 31: GVA (low-high) estimates under the Net Zero Higher baseline

	2030 (£ billion)	2050 (£ billion)
Baseline	7.28 - 38.39	14.78 - 67.77
Scenario 2	7.32 - 38.65	14.81 - 67.96
Scenario 3	7.33 - 38.71	14.82 - 68.01

5.2.4 Wider regional impacts

The socio-economic benefits that may accrue to neighbouring regions were considered based on the potential spillover effects from the economic impacts in those areas directly affected by the increase in the renewables and low carbon infrastructure.

Based on the current pipeline of offshore wind, CCUS and hydrogen projects in the UK, there is a concentration of CCUS and Hydrogen projects in the Humber-Teesside regions as well as Scotland. As job opportunities in these regions grow, better transport and connectivity to these regions can help people in neighbouring areas trade and access these new jobs. It is expected to improve economic opportunities in these areas and benefit neighbouring localities. More generally, large infrastructural developments can have significant knock-on economic opportunities for local areas. Meta-evaluation of the impacts of the London 2012 Olympic and Paralympic games revealed that the Games played a central role in driving the regeneration of East London. The catalytic role of the Games is also apparent in the transformation of public transport in East London. Thus, under scenario 2, with more domestic co-ordination, areas where renewable energy projects develop could receive more attention in terms of policy development and funding for regeneration under the previous UK Government's Levelling Up agenda.

The Government has announced that savings from HS2 will be diverted to create better transport links across the UK. About £36 billion will be reinvested. Scotland will benefit from funding and the provision of better links between the Cairnryan ferry terminals serving Northern Ireland and southwest Scotland. Network North will build better connectivity across the North and Midlands with faster journey times, increased capacity and more frequent, reliable services[62].

A 2023 report estimates that every £1 spent by Hinkley Point Nuclear power plant in Somerset generates £2.50 of value in the local region[63]. This includes an increase in GVA per filled job (2015-2020) of 12.6% in the Bridgewater Travel to Work Areas (TTWA) where the plant is located, and an 8.6% increase in GVA per filled job across the whole of the Southwest. Other wider impacts include an increase in local employment in Sedgemore of 8.5% between 2015 and 2020 and a 13.6% growth in companies. The power plant has trained over 1,100 apprentices and supports the wider community through initiatives such as investing £139m in local infrastructure and establishing a free community bus service in rural Somerset[64]. This demonstrates the potential wider regional impacts that are possible with large energy infrastructure developments.

5.2.5 Increased investment

There are significant investments being made by the UK Government to decarbonise the UK economy and to meet its Net Zero target by 2050. The 'Ten-point plan for a green industrial revolution', together with the 'Net zero strategy' and the Energy Strategy are expected to drive around £100 billion of private sector investment by 2030 into new British industries and support up to 480,000 clean jobs by the end of the decade[65]. Major plans to speed up connections and rapidly increase capacity on the electricity grid have been set out alongside £960 million investment in green industries – strengthening UK energy security and delivering long term savings for families and businesses[66].

Many of the stakeholders mentioned that private developers face a market with multiple barriers such as lack of incentives to cooperate. This could be mitigated with increased international cooperation and policies that facilitate collaboration amongst developers, leading to increased investment flows in the sector overall as well as in the UK more broadly.

In addition, if scenarios 2 or 3 is realised, there is likely to be a reduction in capital costs for offshore renewables construction. There is also the possibility that there will be increased renewable deployment at the extensive margin based on current evidence of additional offshore wind capacity being installed in new locations along the UK coast.[i] In conjunction, under a scenario of increased cooperation, existing interconnection infrastructure could be used to connect newer projects rather than constructing new pipelines and interconnectors. This would be at much lower costs than setting up new infrastructure and would also increase efficiency of the existing infrastructure. The savings could be rerouted to decarbonise other sectors within the UK like retrofitting homes and installing electric heat pumps etc.

[62] https://www.gov.uk/government/news/boost-for-scotland-and-uk-wide-transport-connectivity
[63] https://heartofswlep.co.uk/wp-content/uploads/2023/08/EDF-dashboard-final.pdf
[64] https://www.edfenergy.com/sites/default/files/hpc_socio_economic_report_2023_-_compressed.pdf
[65] https://www.gov.uk/government/publications/british-energy-security-strategy/british-energy-security-strategy
[66] https://www.gov.uk/government/news/huge-boost-for-uk-green-industries-with-960-million-government-investment-and-major-reform-of-power-network#:~:text=Backing%20green%20industries,the%20Green%20Industries%20Growth%20Accelerator.

For this reason, there is a risk of uncertainty around how scenarios 2 and 3 are likely to play out up to 2050.

5.3 Environment

Improving environmental outcomes is at the heart of the UK's decarbonisation strategy[67]. This is why the Government has committed to reduce greenhouse gas emissions to net-zero by 2050. The potential impact on the environment of greater coordination of the offshore renewables and greater international cooperation by assessing the possible changes in carbon emissions and what that might mean for the physical and ecological landscape were considered with focus on impacts to the geographic environment like the impact of renewable energy projects on land and water as well as the potential emissions reductions.

5.3.1 Emissions reduction

Based on the modelling exercise conducted in Section 4, the emission reductions accrued under the two scenarios are explained in Section 4. They can be observed in the following table.

Table 32: Potential emission reduction in scenarios 2 and 3 compared to baselines

Baselines	Known Policy		Net Zero High	
Scenarios	Scenario 2	Scenario 3	Scenario 2	Scenario 3
	$MtCO_2$ 2025-50			
Total CO_2 reduction	37.1	46.3	(1.9)	(0.4)

5.3.2 Spatial impact

The development, construction and operation of the offshore renewable infrastructure are highly likely to impact the surrounding physical and natural environment. To assess spatial impacts, a qualitative review was conducted of potential land use changes, and ecological and visual effects. These impacts may vary depending on the infrastructure. While there could be potential constraints in developing renewable energy infrastructure in the North Sea like supply chain issues and capacity of North Sea ports to support infrastructure development[68], one of the most important challenges is ensuring effective connections of offshore infrastructure to the grid[69].

Land use changes

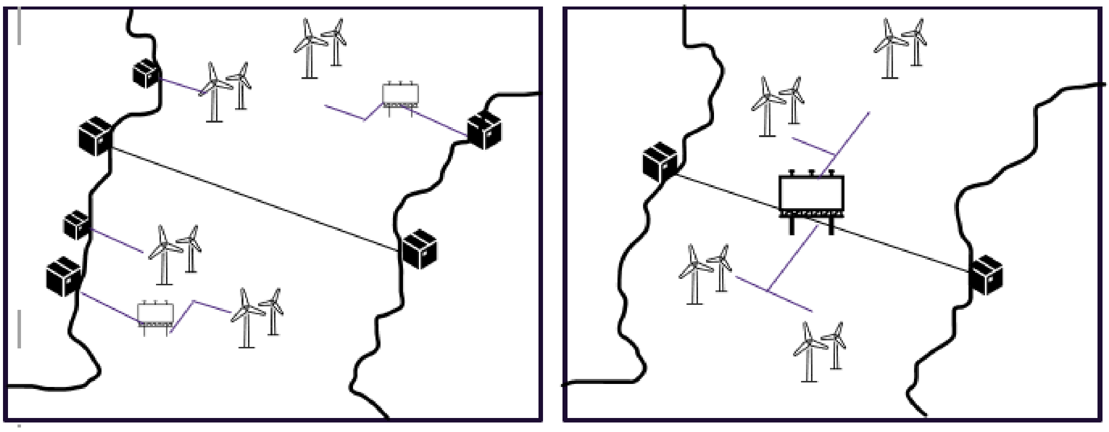
Offshore renewables projects often require onshore infrastructure such as converter stations, manufacturing facilities and transmission lines. These are likely to lead to changes in land use patterns, particularly in coastal areas where these facilities are typically located.

A more holistic operation of offshore wind farms and interconnectors is likely to be facilitated via creation of central offshore 'hubs. MPIs require less infrastructure compared to point-to-point interconnectors. They can connect multiple wind farms to an offshore converter, as well as multiple countries, as illustrated in the right side of Figure 25 below. Under a holistic approach, conversion from alternating current to direct current may be done via an "offshore hub, whereas currently, each offshore wind farm is connected to the shore individually by a point-to-point interconnector. Therefore, the negative impact on land is likely to be less under a more holistic approached as fewer converter stations would be required on land. This relative impact is illustrated in Figure 25 below, whereby the number of onshore

[67] https://assets.publishing.service.gov.uk/media/6194dfa4d3bf7f0555071b1b/net-zero-strategy-beis.pdf
[68] https://eepublicdownloads.blob.core.windows.net/public-cdn-container/tyndp-documents/ONDP2024/ONDP2024-northern-seas.pdf
[69] https://hydrogeneurope.eu/strong-hydrogen-and-offshore-planning-will-aid-grid-constraints/

stations is much less if a more holistic approach is adopted. The impact envisaged is based on theoretical understanding of land usage and cannot be presently quantified.

Figure 25: Differences between baseline scenario (using point-to-point interconnectors) and a holistic approach (use of MPIs)



Ecological impact

A reduction in carbon emissions is expected to have a positive impact on the natural environment. However, there are likely to be some disbenefits relating to the location and operation of the infrastructure that is required to support the movement to a greener economy. For example, in the case of CCUS, there are risks around CO_2 leakage contaminating neighbouring land and unequal benefit distribution from improved water levels[70]. The production of green hydrogen also increases the risk of land use and land cover changes. The generation of the power, from renewables, that is needed for electrolysis, often requires large amounts of land. This could lead to the conversion of natural habitats or agricultural land, which could have negative impacts on biodiversity and food security.

Offshore infrastructure can have significant impacts on marine life. They could create artificial reefs and provide habitats for certain species but may also cause habitat disruption and collision risks for others as well as underwater noise pollution. International cooperation would mean greater levels of infrastructure because of likely creation of larger offshore "energy hubs" that combine international infrastructure (see Figure 1). This would consequently generate greater adverse incremental impact on marine ecosystems compared to the holistic coordination of UK's offshore renewable assets. More cooperation and planning between developers and countries will likely ease competition for limited seabed space in a future that is crowded with renewable energy projects[71].

Visual and aesthetics

The placement of offshore infrastructure near to the coastline can alter the visual landscape, which may negatively impact marine-related recreational activities and property values in coastal areas. Public acceptance of renewable energy projects is linked to the visual and aesthetic impact of the project[72]. This could be a possible issue for green hydrogen projects given their large land requirements and may well have follow-on impacts on public support for Net oero policies more generally. More holistic coordination and greater cooperation could mean offshore infrastructure further out to sea and more efficient infrastructure construction. This would limit the number of converter stations and avoid duplicated infrastructure and as such may reduce adverse visual and aesthetic impacts.

[70] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9345485/
[71] https://blogs.iadb.org/sostenibilidad/en/key-aspects-for-managing-the-environmental-and-social-risks-of-green-hydrogen/#:~:text=Another%20environmental%20risk%20associated%20with,requires%20large%20amounts%20of%20land.
[72] https://www.sciencedirect.com/science/article/pii/S2214629622002444?via%3Dihub

5.4 Policy

5.4.1 Increased security of supply

Security of energy supply is critical to maintaining economic prosperity, protecting public safety and enhancing national security. Despite the prevalence of renewables power generation, natural gas is still the marginal fuel for setting wholesale electricity prices. This is because natural gas-fired power plants are often used to meet the peak demand for electricity, as they can ramp up quickly and are more flexible than other sources. The UK is a net importer of gas and is therefore vulnerable to global forces such as geopolitical tensions, changes in global gas demand and supply disruptions that can impact the price and availability of natural gas.

Coordinated operation of offshore renewables infrastructure is essential in facilitating a diverse range of sources for power generation to keep the GB system flexible and resilient. According to the Winser report, by increasing the pace of the rollout of renewable energy generation projects supported by a reinforced grid, would make the UK more energy independent, whilst protecting consumers against volatile international energy markets and associated price fluctuations. This price stability can incentivise investment by providing further reassurance to firms.[73]

The security of supply potential for each scenario was assessed by looking at the additional GW of power capacity installed. This is not a measure of the degree "security of supply" as by design, all scenarios would meet the security of supply standard of a loss of load expectation (LOLE) OF 3 hours per year.

5.4.2 Reduced wholesale power prices

There are reductions in wholesale power prices due to higher deployment of offshore wind due to holistic domestic and international coordination. This positive benefit on wholesale prices in the Net Zero Higher baseline is not achieved due to the already high offshore wind generation capacity in the baseline assumptions. The trajectory for wholesale power prices across the various scenarios is explained in Section 4 under the modelling outputs.

5.5 Regulatory

5.5.1 Increased market competition at the wholesale level

Market competition at the wholesale level for energy is expected to help keep cost down, promote innovation and facilitate the transition to a decarbonised energy system. More coordination of offshore low carbon technologies and greater international cooperation is expected to increase competition by adding more alternative providers of energy supply. Moreover, offshore low carbon technologies have the potential to become more cost-effective over time (as has been the case for offshore wind). This can, over time, put downward pressure on wholesale prices. The more holistic scenarios that involve a larger market and can also allow for collaboration efficiencies, are likely to increase market competition at the wholesale level.

5.6 Technology

5.6.1 Increased innovation

Increased cooperation under scenarios 2 and 3 is expected to positively impact innovation in the renewable energy sector in the UK. Greater cooperation is likely to result in new and more efficient ways of building and operating these technologies.

[73] Electricity Networks Commissioner: companion report findings and recommendations (publishing.service.gov.uk)

The UK Government in 2023 made a commitment to raise around £22 billion as an investment in R&D, taking it to 2.4% of GDP[74]. However, a likely impact of increased cooperation might be increased investment in renewable energy by both public and private sectors as the market expands. Additionally, the creation of clusters (for CCUS and hydrogen) as well as energy hubs in specific regions of the UK could also enable the development of research centres/ centres of excellence in the universities in those regions.

For CCUS and related infrastructure, each CCUS cluster could be the foundation for a Clean Growth Regeneration ("CGR") Zone, to drive new thinking around CCUS innovation, deployment, investment and how CCUS can integrate with other decarbonisation options to support wider industrial decarbonisation. The CGR Zones can support the Government's decarbonisation and innovation vision, with CCUS clusters anchoring investment in regions, thereby boosting local jobs and skills[75].

The levelised cost of electricity (LCOE) is another important indicator of the progress of energy technology innovation[76]. According to the EINA, grid integration innovations is expected to reduce offshore wind energy system cost as well as the cost of transporting energy over long distances. Innovation around logistics, installations and smarter O&M has the potential include digitalisation and AI, improved data analysis to increase availability and performance improvements by improved control systems and is expected to ultimately reduce financing costs and therefore LCOE.[77]

Under scenarios 2 and 3, there could also be more knowledge-sharing between different countries (within or outside of the UK). Decarbonisation of shipping presents a significant opportunity for innovation and creation of new hydrogen industries and Norway is currently considering the development of hydrogen powered ships[78]. Such pilots and experiments can be adapted and scaled within the UK. Stakeholders highlighted a loss of access to multiple grants that was previously available under the EU. In scenario 3, with greater cooperation, there could be an increased access to grant funding, specifically to push forth R&D in the renewable energy sector.

[74] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1167856/offshore-wind-investment-roadmap.pdf

[75] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/727040/CCUS_Cost_Challenge_Taskforce_Report.pdf

[76] https://strathprints.strath.ac.uk/74462/1/Hannon_Bolton_AP_2021_Energy_innovation_and_the_sustainability.pdf

[77] https://assets.publishing.service.gov.uk/media/5dc588bee5274a4ec1b88794/energy-innovation-needs-assessment-offshore-wind.pdf

[78] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/727040/CCUS_Cost_Challenge_Taskforce_Report.pdf

6 Stakeholder Interviews

6.1 Introduction

To gauge diverse perspectives on UK renewable energy infrastructure and pathways for domestic and international cooperation, 15 stakeholder organisations (such as regulators, trade associations, developers, think tanks, etc) were interviewed in January and February 2024. The list of 15 organisations involved in the interviews were decided in conjunction with DESNZ. Discussions focused on four key infrastructure types: offshore wind, interconnectors, carbon capture and storage (CCUS), and hydrogen. This section summarises the stakeholders' views on how these technologies are likely to develop in the coming decades and the potential barriers to their deployment[79].

Table 33: Participants of the stakeholder engagement by company type

Type	Number
Private Developers	5
TSO - Domestic	2
TSO – European	1
Regulatory Bodies	2
Trade Association – Domestic	2
Trade Association – European	2
Think Tanks	1

Source: Grant Thornton

This exercise was conducted to enhance the holistic scenario development in practice and further understand the impact of critical success factors against which the outputs of this project depend on. The range of diverse opinions put forth by the stakeholders along with any consensus reached, as well as identified needs and priorities from parties involved across the industry is expected to direct future policy and regulatory frameworks to facilitate expected outcomes. This is also expected to allow for an early identification of risks and challenges to develop a holistic energy system more proactively. Furthermore, engagement was also expected to build stakeholders' acceptance of, and confidence in, final recommendations. Fifteen stakeholder organisations comprising of regulators, trade associations, developers, think tanks, etc.

Stakeholders were asked overarching questions that relate to the general picture around the existing pipeline for offshore renewables and how this could change under the holistic domestic and international scenarios. The questionnaire developed for the stakeholder engagement can be found in Appendix A. The following sub-sections summarises the discussions that were held and views expressed by stakeholders.

[79] Please note that these views are strictly the views of stakeholders and does not contain any analysis from Grant Thornton.

6.2 Policy targets beyond 2030

Stakeholders anticipated a "business as usual" approach towards 2030, with existing projects progressing and meeting UK's clear sector-specific targets. However, a stakeholder noted that the overall policy perspective in the renewable energy space was to allow the current pipeline to evolve gradually rather than exploring radical and transformative options. The offshore wind and interconnector markets are perceived as mature and stable. However, uncertainty surrounded the development of hydrogen and CCUS technologies, leading to a cautious wait-and-see approach from stakeholders.

Despite of a lot of policy development underway, stakeholders expressed concern about the UK's current approach, citing its opacity and siloed nature. They highlighted a disconnect between various policy elements, particularly across different sectors. For example, decarbonization targets fall under the Petroleum Act, while offshore wind is linked to CfDs, making it difficult to integrate them with CCUS and hydrogen, which themselves come under a separate act (Petroleum Act) than offshore wind (Electricity Act). Some stakeholders also mentioned misalignment and policy gaps around developing a comprehensive energy system and the environmental impact of current and upcoming projects.

Although the implementation of REMA was perceived to be a step in the right direction, there were significant concerns about the delayed implementation of the OTNR as well as the Energy Security bill, a legislation pertinent to UK's net-zero ambitions.

All the stakeholders agreed that there were benefits arising from domestic and international cooperation. Stakeholders unanimously emphasised the critical need for robust legislation and policy to guide market evolution and cooperation towards 2050. Some of them also stressed on the need to develop a combined policy across different infrastructure types so that they can be linked, wherever necessary to form a comprehensive energy grid.

6.3 Speed of deployment

Many stakeholders remarked that multiple policies in the UK Government's pipeline were a step in the right direction to create an integrated energy market in the country. This included the implementation of REMA wherein the prices included under its remit had implications for all the renewable technologies. Some stakeholders mentioned that implementation of the OTNR was essential as it was expected to facilitate connections and speed up projects.

Additionally, the implementation of the Electricity Network: Connections Action Plan was also considered to be a good starting point on understanding the connections regime and expected to inform better investment decisions.

One of the stakeholders mentioned that the CSNP was crucial as it didn't just look at the grid as static infrastructure, it also considered future infrastructure for hydrogen and CCUS. A successful implementation of the CSNP would help chart a definite path for domestic cooperation and provide some insight around the scope of the creation of 'energy hubs' within the UK.

All the stakeholders had mixed reviews around the UK's CfD regime for Offshore Wind. While some stakeholders believed that the current system needed to be improved to ensure its efficiency, some other stakeholders were of the opinion that an entirely new system, encompassing Offshore Wind, CCUS and Hydrogen would be a better approach in the future. However, most of the stakeholders agreed that the 6th CfD Allocation round was an improvement on the previous round.

The implementation of HND (Holistic Network Design) provides a strategic blueprint for the coordinated connection of 23GW of offshore wind to the network by 2030. The HND will be followed by the CSNP, to be delivered in 2024-2025 by the new independent National Energy System Operator (NESO). The CSNP is intended to provide a blueprint for the whole transmission network to enable coordinated and accelerated network development, including alignment between onshore and offshore networks.

6.4 UK's Renewable Energy market

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6.5 Domestic coordination and cooperation

Many stakeholders advocated for adopting a holistic approach at the domestic level. While some stakeholders believed that there was a need to focus on domestic coordination before moving to international cooperation, others believed both needed to happen simultaneously. Stakeholders pointed out various challenges around policy, finance and supply chains currently existent in the market hindering the path to cooperation.

6.5.1 Strategic coordination across devolved nations

Most stakeholders highlighted that there was an urgent need for England, Wales and Northern Ireland to work cohesively as well as aligning with Scotland to develop their renewable energy projects. There was also a directive for using more strategic forethought when it comes to offshore grid arrangements, which can be developed further as the Hydrogen and CCUS markets develop.

Some stakeholders mentioned that some Scottish projects show a lot of forethought around OSW grids and that this should be adapted across the UK as it will allow new grid development considerations in areas where grid deployment is easy and efficient. There were a few stakeholders who also urged the inclusion of Ireland in establishing grid connections.

6.5.2 Cohesive Policy

One stakeholder mentioned that the UK is currently focussed on meeting infrastructure targets through internal policy action and issues. They cited issues working with devolved Governments translating concepts such as net gain, marine recovery etc. in context of Wales, Scotland and Northern Ireland.

Another stakeholder urged that the UK Government needs to ensure that all the relevant organisations have goals and targets that are not contradictory. Different entities like OFGEM, DEFRA, etc. have different objectives and hence differing policies resulting in developers being left to piece everything together in terms of differing project requirements which is cumbersome.

A private developer based in the UK urged the need for holistic support in project development. They stated that the UK renewable energy ambition currently depends on notable investment demands from third parties without much financial and legislative support. They stated that developers would need to navigate the project development and delivery based solely on their own insights.

A stakeholder mentioned that there isn't much foresight on seabed leasing beyond the current year or not even on operational risk in the newly proposed HND. There are a couple of things that the UK needs to do before it takes up widespread creation of energy hubs. One is seabed mapping: it needs to have a national mapping of available seabed and some sort of database chronicling their usage. Second is security of renewable energy infrastructure – there have been instances of sabotage of gas pipelines (in the Baltic countries as well as an incidence around the pipeline in Shetland).

6.5.3 Incentive for collaboration

Most stakeholders agreed that the energy market in its current state does not incentivise collaboration. Additionally, there are currently no pricing mechanisms that allow any coordination. UK expects market coordinate in order to deliver on Government priorities (e.g. supply chain investment) which is unrealistic as the same market participants are in competition in other markets.

6.6 Internation coordination and cooperation

6.6.1 Network planning

While all stakeholders agree international cooperation on renewable energy in the North Sea is beneficial, opinions diverge on its feasibility. Some wholeheartedly support collaboration, citing shared energy needs and regional market maturity. Most stakeholders agreed that eventually there will be a need for an integrated energy grid that works around the flexibility of the power system.

Stakeholders noted an increased political willingness for cross-border discussions. The European Union's approach for an integrated energy market necessitates UK involvement and exploring opportunities through joint discussions. Moving forward, navigating these complex considerations will be key to unlocking the benefits of international collaboration.

A stakeholder noted that the recent North Sea Energy Cooperation Summit exemplified this political willingness. However, concerns exist about post-Brexit hurdles, particularly in standardising policies and achieving concrete outcomes beyond information exchange.

Additionally, many stakeholders believed international cooperation is crucial to the development of the UK's market for MPIs, CCUS and hydrogen production. One of the stakeholders suggested that adequate international demand and the support of domestic legislation could potentially allow the UK to become an exporter of hydrogen, with positive implications for job generation. Another stakeholder stressed on the North Sea grid being crucial for the facilitation of CCUS and Hydrogen energy trade. Another stakeholder mentioned that this would allow UK to gain a trade advantage whilst also being in line with its climate agenda. Hence the Government should step up its efforts in developing these technologies and putting international cooperation in place.

A stakeholder, a private developer, expressed an inclination to work towards hybrid interconnectors from windfarms to North Sea countries. They further noted that coordination helps when windfarms are built with same connectors to maximise asset impact. This location and spatial planning will also have a positive impact on the cost of network.

Most stakeholders remarked that trade policy, port usage, supply chain cooperation, market frameworks, technological targets and financing options will be the key in shaping up international agreements. This is also linked to each Government's specific goals as it will help streamline and speed up development of investment and approval process for projects.

Most stakeholders remarked that there is no real advantage to the UK from refraining to cooperate. While there is a possibility of achieving self-reliance in terms of offshore wind and possibly hydrogen, but the UK will inevitably need to work with the EU either for its production or distribution needs. Hence it is preferable to establish planning and trading arrangements as soon as possible.

6.6.2 Distribution of costs and benefits

The key question around international or cross-country energy projects is around the distribution of costs and benefits. One of the stakeholders stressed the importance of pan-national agreements that provide a draft framework for funding, investment and cost-sharing to be put in place, not just with North-Sea but with the wider set of European countries as well.

For international cooperation, there needs to be more policy around cost and benefits sharing. Exporting countries don't want to pay for CfDs – this leaves countries with no choice but cooperation. There is scope for bilateral treaties.

6.6.3 Supply Chains

Some stakeholders noted that a significant opportunity for collaboration was required across the supply chain to reinforce the grid and build capacity. They stressed the need for joint procurement and block tendering as key to achieving supply-chain cooperation.

They also cited examples of agreements to create European supply chains for offshore wind equipment and the fact that UK is not involved these agreements putting it at a disadvantage. They also stated a need for regulation to manage the pace of project development, colocation of projects and technology standardisation which will need to be symmetric across the supply chain.

6.6.4 Technological standardisation

Some stakeholders pointed out that standardised regulations for ports, planning, and other areas can significantly smooth international cooperation and trade in renewable energy infrastructure. Despite its apparent value, technical standardisation is lagging compared to expectations. Policies promoting harmonisation across borders are needed.

Pre-Brexit initiatives like standardised marking requirements for offshore turbines remained incomplete, highlighting the need for renewed focus and coordinated action. One stakeholder pointed out that continued involvement in discussions on standardisation with the EU, particularly regarding HVDC and interconnectors, remains strategically important.

Standardisation across grid components was cited to be critical for overall grid design, however a stakeholder noted an absence on any pan-NSEC policy around it. They also put forth a proposal to retrofit existing oil and gas technology so that renewable projects can be developed in existing site.

6.6.5 Grid connections

The actual assets for connection need to be built as currently these are not even in place – coordination doesn't matter until this has been done. A stakeholder stated that there is a lack of a regulatory framework in Europe with respect to interconnectors (i.e. MPIs/OHAs). According to them, this is the single most important element why EU member states and the UK should be well-aligned. There is no logic in adopting two different approaches when they are intrinsically international operations.

6.6.6 Observer status

Currently, the UK needs to establish at least an observer relationship with the ENTSO-E to become a part of the single energy market. One of the stakeholders remarked that basic agreements through MoUs are a good starting place but additional involvement is necessary for the UK Government to have a deeper understanding of the European energy markets and the scope for collaboration.

6.6.7 Loss of influence

Exiting the EU also meant leaving ENTSO-E, the European electricity network association. This limits UK's involvement in crucial planning processes like the TYNDP, leaving them unable to critically engage in decisions that directly impact them.

6.6.8 Spatial considerations

There are some growing concerns surrounding competition for limited seabed space in a future crowded with renewable energy projects. Countries need to proactively discuss and develop international policy frameworks to address this. Such frameworks would not only facilitate collaboration and optimise space utilisation, but also enable environmental impact assessment and address limitations of individual nations, ensuring efficient progress towards shared decarbonisation goals.

6.6.9 Price coupling

Some stakeholders suggested rejoining the EU's single market price coupling mechanism would be more efficient than explicit trading, especially for scenario 3. However, this requires a close economic relationship with the EU, raising questions about its feasibility after Brexit.

6.6.10 Implicit trading challenges

While the UK-EU Trade Cooperation Agreement (TCA) permits implicit trading, industry experts view it as impractical. The Government needs to address this gap.

6.7 Access to finance

Some stakeholders highlighted the need of Government funding for the renewable energy sector. The decision of leaving the EU resulted in a loss of significant EU grant funding. Hence potential grants from the Government and other organisations would help bridge a part of this gap. There is also a need to implement a robust subsidy regime, especially for the development of Hydrogen and CCUS projects in the UK.

Some stakeholders discussed the role of Transmission System Operator (TSO) and their ability to raise capital. They also highlighted the need for a revenue stabilising mechanism for renewable energy projects. Citing high developer capital needs, they stated that lowering borrowing costs is crucial. They emphasised that as long as funding includes support mechanisms, the source shouldn't matter, ultimately channelling the benefits back to the funding organisations.

One stakeholder also remarked the absence of Green finance regulation / taxonomy in the UK which is crucial for efficient investment utilisation. They also added that some of the funds should also be earmarked for industries and organisations that need to be decarbonised in order to reduce carbon emissions at the economy/national level. Overall, the Government needs to ensure that taxonomies are set up correctly to deliver the transition, using companies with genuine green plans.

6.8 Supply chain

According to a stakeholder, a major risk to UK's renewable energy plans (specifically, offshore) is through disrupted supply chains. Another one noted that connection time for new infrastructure is still a decade away – hence, newer infrastructure won't be efficiently utilised until it is all connected.

While another one also highlighted that securing a well-functioning supply chain would decrease cost for the project, by ensuring symmetry in supply. Another stakeholder advocated for joint procurement and overhauling the supply chain. They mentioned that this will help make the supply chain efficient and help with the increasing rate of production nearer to the 2030 target.

6.9 Renewables, low carbon technologies and related infrastructure

6.9.1 Offshore Wind

Most stakeholders well-versed with the Offshore Wind energy market agreed that it is the most mature market in the UK in terms of renewable energy. They believed that future leasing will be done in contemplation of NESO energy planning. Another stakeholder remarked that the current pipeline for OSW reflects the potential for the UK to meet its 2050 OSW targets.

While some private-sector stakeholders stated that a holistic domestic scenario is well underway, majority believed the current market doesn't allow for coordination. Stakeholders, especially private developers stated that there is little incentive to cooperate since the developers are competing at CfDs and for capacity on the National Grid. One stakeholder proposed using an anticipatory investment and cost recovery model stating that it could encourage cooperation.

Stakeholders also highlighted the need for a more strategic approach which delivers networks that consider both on and offshore networks in a coordinated way allowing for greater scope for coordination between energy vectors.

The purpose of the HND was to move to more coordinated projects and energy hub-style setup, but ambition seems to have pulled back. E.g. Scotland and Celtic Sea seems to be less coordinated than planned: at least one radial connection rather than originally planned interconnections. Stakeholders remarked the willingness to promote coordination but not having the desired results.

However, there were certain areas of concern highlighted by the stakeholders. There is some uncertainty around supply chain challenges for manufacturers, especially the ones who don't have massive presence in the UK.

There is a need for a clear definition of offshore bidding zone as there is not enough clarity on how this would operate in practice.

6.9.2 Interconnectors

Many stakeholders believed that MPIs and non-standard interconnectors are notable advancement in technologies, and they contribute to increased infrastructure security because there is no one single point of failure. They help derive maximum benefits from having more projects in one place offshore.

Another stakeholder stressed the importance of interconnection in managing wind production. If the wind just stops in one area, production can be balanced by the projects in other regions – this back up is critical so interconnectors play a key role in network capacity.

However, stakeholders remarked that Ofgem's cap and collar regime doesn't currently incentivise the use of point-to-point over radial or MPI. Hence, the choice is left to developers and the complex market arrangement is also very helpful.

Some stakeholders characterised the UK interconnectors market as merchant operating in a sector devoid of a national and centralised plan. Policies and rules differ across jurisdictions, payments systems and asset bases hence it is difficult for developers and merchants to get clarity around project planning and investment.

Many stakeholders agreed that effective functioning of MPIs still needs policy change in addition to CfDs and the existing cap and floor regime, as the CfD regime makes it difficult to determine ownership and separation of assets.

One stakeholder noted that the proposed pilot cap and floor scheme, separate to the established cap and floor scheme for traditional interconnectors, will help improve market conditions.

Some stakeholders also remarked that complex projects involving MPIs, especially at the international level will need bespoke arrangements which will be possible only through international collaboration.

6.9.3 CCUS

Many stakeholders believed that UK could become an importer of CO_2, but it will need to be supported by a backbone of strong regulation, incentives and a well-planned network design. The CCUS Vision Document which sets out plans for new competitive market in Carbon Capture, Usage and Storage (CCUS) by 2035 is a good starting point for progressing the market.

One stakeholder remarked that emerging technology (CCUS/hydrogen), by design, take a holistic approach with their clusters. Hence, they urged the need to properly marry UK's industrial policy and its decarbonising strategy as well as the policy for developing CCUS capacity. They believed that this would help set the demand and supply expectations for CCUS and hydrogen.

The stakeholders added that importing CO_2 can help decarbonise England-based clusters with some stakeholders proposing the creation of an importing hub in Scotland.

Another stakeholder remarked that there were currently a few clusters being developed in the UK with slight variations across each of the clusters. They remarked that this asymmetry staggers innovation and contributes to capacity imbalances. It also must be noted locational planning of the storage facilities must be improved since not all industrial bases have access to storage facilities.

Another stakeholder remarked that the oil refineries, especially across Wales and Southampton will have CO_2 reserves and that there needs to be a plan in place for a collaboration with the oil refineries and the CCUS hubs.

6.9.4 Hydrogen

Many stakeholders believed that UK has a significant potential to export hydrogen and import CO_2 but there is a long way till UK is ready is for producing enough to meet international demand. There is a need for guidance on how common assumptions, technologies and understandings will be applied over long-term.

Another stakeholder remarked that very few financial decisions have been reached for hydrogen. To stimulate the market, clear and binding targets are required. But there is a reluctance to uptake at the start given the high setup costs for these projects.

Some believed that the market for hydrogen is very nascent but as hydrogen economies develop there should be a knock-on effect for prices. Additionally, some stakeholders remarked that UK is set for fairly expensive early auctions, though as clusters and networks therein develop, prices may fall. Additionally, UK has the potential to produce more hydrogen than several other countries, in the long run, owing to availability of cheap electricity from Scotland.

Some stakeholders were also of the opinion that international cooperation and competition will bring prices down. They argued that the key component of hydrogen price is electricity price so an increased deployment of renewables will reduce electricity prices which will have a knock-on effect on hydrogen price. Renewable hydrogen price is also dependent on technology cost; as this is deployed more, this will also depress the price.

Another stakeholder pointed that there is a challenge around hydrogen production due to limited engagement and Government support. They suggested following the example of the USA which makes use of a basic tax system. Further they added that regulatory certainty and the creation of market tax-credits will help make this technology more attractive for private developers and investors.

The UK Government has set a production target of construction of 10GW of low carbon hydrogen production capacity by 2030 and at least half of this is expected to be from renewable energy source. There is also work being undertaken around hydrogen allocation rounds and on the development of standards and certification. This is useful since the stakeholders remarked that market is unlikely to deliver without any Government signalling. However, the stakeholder also warned against heralding Hydrogen technology as the easy solution for the UK's net-zero ambitions and energy needs. The UK Government also needs to evaluate its Hydrogen-related policy in terms of the trade-off between market making and energy security.

Another aspect of UK's hydrogen production is that it is supported by UK government subsidies. Hence export of hydrogen that was produced using Government subsidies is a complicated policy situation that has no easy solution.

There is a focus on skills to see if Government is providing enough to help upskill people to work in hydrogen. But there may be a bottleneck in terms of skills. At some point this year there will be a Green Jobs Plan coming out.

For international cooperation and hydrogen, the main question is on certification of clean hydrogen. There is need to have consistent standards internationally. (Brazil, Chile and USA have some experience in this space.)

A stakeholder highlighted Denmark as a case-study and whether the UK could take some learnings from the Danish policy around hydrogen which is very forward leaning and focuses more on export rather than domestic use.

7 Appendix A: Stakeholder interview questions

7.1 Overarching questions

These questions were tailored to the stakeholder being interviewed.

i. How do you envisage policy and market structure surrounding [CCUS/ hydrogen/ interconnectors/ wind] will develop up to 2030 and beyond?

ii. How could a holistic approach be adopted domestically to better coordinate across technologies to reach the UK's 2030 deployment goals, and beyond up to 2050? Market arrangements, policy objectives, pricing mechanisms, investments etc.

iii. How could international cooperation benefit the UK in reaching its 2030 deployment goals, and beyond to 2050, in each of these technologies?

iv. Specifically, how are (i) a holistic approach and (ii) international cooperation approach to [CCUS/hydrogen/interconnectors/wind] likely to impact upon network capacity, speed of deployment, cost of the network and capital costs of plants themselves?

v. General view is that greater coordination is required. What, in your mind, is needed to take this to a step change – i.e., moving away from more of the same towards a fundamentally different approach – which will require new regulation, legislation and risk sharing – but if done correctly, could unlock significant untapped potential?

7.2 Infrastructure specific questions

Offshore Wind

i. To what extent does the existing pipeline of offshore wind production involve coordination with interconnector projects or other renewable projects e.g. OSW stations connected via MPIs, involving coordinated consenting/planned for shared connections?

ii. What do you envisage as the key changes from current policy to get to a holistic approach that involves domestic coordination across projects? E.g., standardisation of connections that accept more than one generation site (rather than being point-to-point).

iii. What do you envisage as the key features of enhanced international cooperation in offshore wind? E.g. international connections via MPIs/ coordinated planning with non-GB projects/ energy "hubs" that incorporate GB and non-GB projects etc. and with which countries?

iv. Are there changes to approach or other drivers (i.e. new technologies) which give you confidence that new approaches to infrastructure may work in this decade? Given the undoubted ambition – is a radical approach now required?

v. Are there changes to approach which would facilitate a holistic energy system? E.g. proliferation of floating windfarms affecting seabed leasing and (opportunity cost of) cooperating with other technologies.

vi. Do you foresee any barriers to successful project coordination as per current offshore wind ambitions, for example, any issues with seabed leasing, financial, intellectual property rights, funder requirements or policy coordination?

Interconnectors

i. To what extent does current policy incentivise the use of multi-purpose interconnectors and non-standard interconnectors over point-to-point interconnectors?

ii. What are your views on how the UK's interconnectors regime is developing? What do you think benefits to security of supply and other environmental and socio-economic factors will be?

iii. At what pace do you envision the deployment of interconnectors occurring? Are there any barriers to success?

iv. Do you foresee any barriers to successful project coordination as per current interconnector ambitions, for example, any issues with seabed leasing, financial, intellectual property rights or policy coordination?

CCUS

i. How could increased coordination of transport of CCUS in North Sea facilities take place?

ii. How could transport of non-GB captured carbon to GB storage facilities take place?

iii. How will CCUS technologies interact with energy "hubs" under each scenario?

iv. Do you foresee any barriers to CCUS deployment e.g. delays to cluster sequencing, ambiguity around ambitions and funding, skills gaps etc.

Hydrogen

i. To what extent could it be possible for hydrogen producers to sell direct to European markets – and which of these markets are a priority? Which European electricity markets could GB projects access for hydrogen production?

ii. How do you envisage the development of hydrogen allocation rounds in the UK, for example through the use of various CfD configurations? How is this likely to compare to other North Sea countries?

iii. How could energy "hubs" connecting multiple countries use surplus electricity to produce hydrogen under European coordination? Is there thinking going into ambitious cross-border thinking such as this?

iv. How will hydrogen technologies interact with energy "hubs" under each scenario?

v. How would domestic vs international coordination impact hydrogen prices, and how could this affect the system more broadly?

vi. Do you foresee any barriers to successful project coordination as per current hydrogen roadmaps, for example, any issues with coordination in planning, funding and clarity of ambition etc.?

8 Appendix B: Methodology for jobs and GVA estimation

As part of the Section on Impact Analysis, the jobs and GVA generated were estimated under the baseline scenario 1, and scenario 2 and 3. This annex provides further detail on the data, assumptions and the methodology underpinning the estimation of the impact on jobs and GVA.

8.1 Methodology

- The methodology is adapted from the methodologies used in two published reports. They are as follows:
  - The Energy Innovation Needs Assessment studies (commissioned by formerly BEIS, now DESNZ)[80]
  - Net Zero Teesside Economic Benefits (prepared for Net Zero Teesside)[81]
- The methodology uses deployment figures for each technology and the associated costs (capital Expenditure) and O&M (Operations and Maintenance costs) etc, to determine the estimated turnover in a year from a given technology.
- Then a relevant share of this turnover, which accrues to the UK, is determined using secondary data and literature reviews.
- Then the appropriate GVA and job multipliers from the ONS databases on Productivity, Low Carbon and Renewable Energy Economy, Environmental Goods and Services Sector, etc. are applied to calculate job and GVA estimates.

8.2 Data

- The data on deployment in GW (Giga Watt terms), capital expenditure (Capex), and operations and maintenance costs (O&M) per KW (Kilo Watt) for Offshore Wind (Floating and Fixed), Carbon Capture Utilisation and Storage, and Hydrogen infrastructure technologies were derived from the modelling assumptions of this project for the period 2025 to 2050. This can be found at the end of the Appendix.
- The data pertains to deployment under two baseline scenarios – Known Policy and Net Zero Higher Electrification. The main difference across these two scenarios is in terms of different deployment capacities for Offshore Wind and CCUS. The deployment of both Offshore wind and CCUS is higher in the Net Zero Higher scenario.
- Costs and deployment figures for CCUS pertain only to the amount of CCUS used in the power sector. For Hydrogen, the data refers to both Blue and Green Hydrogen. However, since the Hydrogen sector is nascent, the numbers in the inputs may vary in the future.

[80] https://assets.publishing.service.gov.uk/media/5dc588bee5274a4ec1b88794/energy-innovation-needs-assessment-offshore-wind.pdf
[81] https://www.netzeroteesside.co.uk/wp-content/uploads/2020/06/20200508_NZT_Economic_Benefits_Report_Edited_Clean_web.pdf

- The data to determine the level of UK content in the inputs for these infrastructure technologies has been taken from the Energy Innovation Needs Assessment reports. These reports have infrastructure-specific reports for Offshore wind[82], CCUS[83] and Hydrogen[84].
- The data on job multipliers which provides FTE (Full Time Equivalents) per million pounds was sourced from ONS[85].
- The GVA per worker was sourced from two sources and both statistics were used to provide a range for GVA contribution estimates. The two sources are noted below
  - Region by Industry labour productivity[86]
  - Environmental goods and services sector (EGSS) estimates[87]

8.3 Assumptions

- O&M costs were provided as Fixed and Variable for each of the technologies but for the purpose of this analysis only Capex costs and O&M Fixed costs are used. This was done because the developers would have to incur these costs in a given year to enable production. Additionally, variable O&M costs are given based on £/Megawatt Hour which cannot be appropriately applied to the deployment numbers which are in GW terms. This means that the estimate for jobs and GVA is on the conservative side and additional jobs as well as GVA is expected to be generated when these variable costs are taken into account.
- Variable O&M costs (per KW) for Offshore Wind and CCUS are less than 15% of Fixed O&M costs (per KW) and hence this wouldn't allow for job and GVA estimates to increase drastically. However, for Hydrogen, variable O&M costs are higher compared to Fixed O&M costs hence the jobs and GVA generation from Hydrogen is notably under-estimated in the analysis.
- The share of UK content in the turnover derived from the sources mentioned above has been assumed to be constant for the entire period of the analysis (2025 to 2050) for CCUS and Hydrogen. The share of UK content in the turnover for Offshore Wind increases in 2030 as noted in the EINA report but then stays constant till 2050. This is because there was no notable source that would provide insight on how the share of UK content might increase in the future and the rate of this growth.
- There are two job multipliers obtained from the ONS data set.
  - One statistic refers to the FTE per £ million for the Electric power generation, transmission and distribution sector (SIC code: D351). This employment effect is used for job estimation from the Offshore Wind technology. (FTE per £ million: 1.018)
  - The other statistic refers to the FTE per £ million for the Manufacture of industrial gases, inorganics and fertilisers (inorganic chemicals) (SIC code C20A). This employment effect is used for job estimation from the CCUS and Hydrogen technologies. This employment effect is higher than the previous and was used for these two technologies as there are growing technologies and are expected to create jobs more rapidly than Offshore Wind. (FTE per £ million: 2.304)
- The GVA per worker obtained from the 'Region by Industry labour productivity' dataset is the GVA/ per worker in 2019 for the ABDE: Non-manufacturing Production and Agriculture sector which is a

[82] https://assets.publishing.service.gov.uk/media/5dc588bee5274a4ec1b88794/energy-innovation-needs-assessment-offshore-wind.pdf (pg. 46 and 46)
[83] https://assets.publishing.service.gov.uk/media/5dc5872be5274a4f2286fc76/energy-innovation-needs-assessment-ccus.pdf (pg. 58)
[84] https://assets.publishing.service.gov.uk/media/5dc587c3ed915d394d60c556/energy-innovation-needs-assessment-hydrogen-fuel-cells.pdf (pg. 63)
[85] FTE multipliers and effects, reference year 2019 - Office for National Statistics (ons.gov.uk)
[86] https://www.ons.gov.uk/economy/economicoutputandproductivity/productivitymeasures/datasets/industrybyregionlabourproductivity
[87] https://www.ons.gov.uk/economy/environmentalaccounts/datasets/ukenvironmentalgoodsandservicessectoregssestimates

broad sectoral statistic including the renewable energy production sector. This forms the lower bound for estimating GVA. [GVA per worker: £ 109,593]

- The GVA per worker statistics obtained from the 'Environmental goods and services sector (EGSS) estimates' pertain to two data points. Since these are more specific to this estimation and are higher than the other GVA per worker statistic, they form the upper bound for estimating GVA.
  - One data point is the GVA per worker in the 'Production of renewable energy sector'. This data point is used in the estimation of GVA from the Offshore Wind and Hydrogen technologies in this analysis. [GVA per worker: £ 613,130]
  - The other data point is the GVA per worker from the 'Environmental low emission vehicles, carbon capture and storage, and inspection and control' sector. This statistic is used in the estimation of GVA for the CCUS technology. [GVA per worker: £ 121,885]
- For Offshore Wind, under scenario 2, based on LCP modelling, there is an 8% increase in deployment capacity and a reduction in system costs of 18%. Under scenario 3, there is a 10% increase in deployment capacity and a reduction in system costs of 18%.
- For CCUS, under scenarios 2 and 3, based on LCP modelling, there is no change in deployment capacity but a reduction in system costs by 6.5%.
- For Hydrogen, under scenarios 2 and 3, based on LCP modelling, there is no change in either deployment capacity of system costs.

Table 34: Assumptions for each technology under each scenario

	Offshore Wind	CCUS	Hydrogen
Baseline	BAU	BAU	BAU
Scenario 2	8% increase in capacity 18% reduction in system costs	6.5% reduction in system costs	Same as baseline
Scenario 3	10% increase in capacity 18% reduction in system costs	6.5% reduction in system costs	Same as baseline
% of UK content in turnover	2025-2029: 48% 2030-2050: 60%	2025-2050:64%	2025-2050: Capex: 15%; O&M: 95%
FTE (per £ million), 2020	1.018	2.304	2.304
GVA per worker (ONS Productivity data), 2019	£109,593	£109,593	£109,593
GVA per worker (Environmental goods and services sector data), 2020	£613,131	£121,885	£613,131

8.4 Estimation

Based on the modelling in Section 4, the scenarios are described as follows.

For the baseline (Known Policy or Net Zero Higher):

- For Offshore Wind, firstly, costs given in £/ KW terms are converted to £/ GW terms by using the appropriate multiplying factor.
- Then the costs (£/GW) are multiplied by the deployment to estimate market turnover in a given year.
- Then the assumption on % of UK content is applied to estimate turnover captured by UK firms supplying to the UK market.
- Then the assumption on the Employment effect is applied to estimate jobs demanded in a given year.
- This job number is then multiplied by the GVA per worker estimates to provide a range of estimated GVA generated in a given year.
- The GVA estimates are divided by deployment in a given year to provide a range of GVA/ GW estimates.
- This process is replicated for CCUS and Hydrogen deployment.

For scenario 2

- For Offshore Wind, according to the modelling outputs presented in Section 4, an 8% increase over the 2050 deployment capacity is calculated and this increase is uniformly added to the deployment capacity from 2025 to 2050.
- Additionally, Capex costs are reduced by 18% from 2025 to 2050.
- A similar process is repeated as mentioned above to estimate job numbers.
- For GVA under this scenario, the GVA per GW estimates calculated in the baseline are applied to estimate the range of GVA generated in the economy in a given year.
- For CCUS, according to the modelling outputs presented in Section 4, Capex costs are reduced by 6.5% from 2025 to 2050 and the same process is replicated as for Offshore Wind.
- For Hydrogen, according to the modelling outputs presented in Section 4, there is no change as compared to the baseline so the same methodology as the baseline is followed.

For scenario 3

- For Offshore Wind, according to the modelling outputs presented in Section 4, an 10% increase over the 2050 deployment capacity is calculated and this increase is uniformly added to the deployment capacity from 2025 to 2050.
- Additionally, Capex costs are reduced by 18% from 2025 to 2050.
- A similar process is repeated as mentioned above to estimate job numbers.
- For GVA under this scenario, the GVA per GW estimates calculated in the baseline are applied to estimate the range of GVA generated in the economy in a given year.
- For CCUS, according to the modelling outputs presented in Section 4, Capex costs are reduced by 6.5% from 2025 to 2050 and the same process is replicated as for Offshore Wind.
- For Hydrogen, according to the modelling outputs presented in Section 4, there is no change as compared to the baseline so the same methodology as the baseline is followed.

8.5 Estimated results

Table 35: Job estimates under the Net Zero Higher scenario

	2022	2030	2050
Baseline	20,094[88]	66,400	134,900
Scenario 2		56,300	115,800
Scenario 3		56,400	115,900

Table 36: GVA estimates under the Net Zero Higher Electrification scenario

	2030 (£ billion)	2050 (£ billion)
Baseline	7.28 - 38.39	14.78 - 67.77
Scenario 2	7.32 - 38.65	14.81 - 67.96
Scenario 3	7.33 - 38.71	14.82 - 68.01

Table 37: Job estimates under the Known Policy scenario

	2022	2030	2050
Baseline	20,094[89]	60,500	42,100
Scenario 2		51,000	35,800
Scenario 3		51,000	35,800

Table 38: GVA estimates under the Known Policy scenario

	2030 (£ billion)	2050 (£ billion)
Baseline	6.63 - 36.47	4.61 - 25.15
Scenario 2	6.64 - 36.51	4.62 - 25.18
Scenario 3	6.66 - 36.58	4.63 - 25.24

[88] Sourced from various sources like OWIC, LCREE, etc.
[89] Sourced from various sources like OWIC, LCREE, etc.

8.6 Limitations of the Estimation Methodology

- Underestimations for jobs and GVA due to only including Capex and O&M costs – this is more notable for the job and GVA estimations for Hydrogen.
- Since the share of UK content is held constant, this is also leading to possible underestimation as the share of UK content might go up, especially in scenario 2 as greater co-ordination helps boost supply chains and other production processes in the UK thus allowing it to capture the higher share of the turnover. However, there is also a possibility that over time, the share of UK content might reduce, possibly because manufacturing hubs develop in other countries with either cheaper raw materials, cheaper labour or higher technological innovations. In this case, the GVA generation in the analysis could be overestimated.
- The employment effect estimates and the GVA per worker estimates are held constant throughout the period of the analysis. This is because there is no evidence around how employment effect and GVA per worker is expected to grow for these specific technologies in the future.
- As these technologies are deployed on a wider scale in the future and with more technological innovation, system costs for energy production using these technologies might decrease. This could either decrease the demand for jobs or slow down job growth for these technologies. There is however a possibility that system costs might increase in the future due to some input shocks or wider macroeconomic shocks (e.g. tightening of the labour market) which might increase the demand for jobs.
- While the number of jobs supported is higher under the baseline, it must be noted that these are estimates based on expected deployment and currently there are many barriers to such rapid deployment thus adding a higher level of uncertainty over such high job creation potential. However, under scenario 2 and 3, while job numbers might be slightly lower, there is more certainty around the possibility of job creation as many stakeholders are expected to be working in co-ordination to achieve increased deployment of renewable energy resulting in more efficient use of capital and labour resources.
- However, it is rational to assume that as these technologies are deployed on a wider scale, there would be efficiency gains which are likely to increase GVA per worker. This would mean that while job creation from these technologies might slow down, the GVA per worker is expected to increase. This would lead to higher GVA generated in the economy. Thus, the GVA estimates from the analysis underestimate the GVA generating potential from these technologies in the future.
- There is not much change in the GVA estimates for scenario 2 and 3 compared to the baseline. This is primarily because the changes in scenarios 2 and 3 are mainly policy-related changes. Additionally, a significant impact of these changes is seen through a higher utilisation of offshore hybrid assets (such as multipurpose interconnectors). This doesn't have any significant impact on job creation or GVA generation but mainly impacts transmission and thus the wholesale price of energy. Thus, due to the specific way in which scenario 2 and 3 is modelled, the additional impact on GVA is very limited in this impact analysis.
- Under the Known Policy baseline, GVA generation under the longer term is less than in the short term due to a decrease in the deployment of Offshore Wind from 2033 onwards. Hence, a reduction in deployment coupled with lower costs, reduces the GVA generation under this methodology. Again, with increased efficiency, the GVA per worker might increase, leading to higher GVA generation than estimated in this analysis.
- The estimates from this analysis were compared with the Green Jobs Workforce estimates consolidated by DESNZ from various sources. These workforce estimates calculate both direct and indirect jobs while this analysis only estimates direct jobs and hence there is a conceptual difference between the figures. Additionally, it must be noted that there is a difference in methodology adopted in the estimation of the two workforce estimates which could also contribute to the difference in job numbers.

Table 39: Comparative job estimates for offshore wind

	NZHE – Offshore Wind (Direct jobs)			OWIC[90] (Direct Jobs)	OWIC (Direct + Indirect Jobs)
	Baseline	Scenario 2	Scenario 3		
2022				17,394	32,257
2030	59,100	49,300	49,400	56,296	104,401
2050	100,500	83,400	83,500		

Table 40: Comparative job estimates for CCUS

	NZHE – Offshore Wind (Direct jobs)			Various Sources (Direct + Indirect jobs; most jobs in Construction)
	Baseline	**Scenario 2**	**Scenario 3**	
2023				700[91]
2030	4,700	4,400	4,400	26,500[92]
2050	30,400	28,500	28,500	

[90] https://www.owic.org.uk/_files/ugd/1c0521_94c1d5e74ec14b59afc44cebe2960f62.pdf
[91] RGU Energy Transition Inst./ Opergy estimate
[92] https://www.lse.ac.uk/granthaminstitute/wp-content/uploads/2021/09/Seizing-Sustainable-Growth-Opportunities-from-CCUS-in-the-UK_8_PAGE-BRIEF.pdf

9 Appendix C: Glossary

Term	Definition
BEIS	Department for Business, Energy and Industrial Strategy
Capex	Capital Expenditure
CCUS	Carbon Capture, Utilisation and Storage
CfD	Contracts for Difference; a contractual mechanism designed to incentivise investments in renewable energy projects in the UK at the least cost to the consumer
CGR	Clean Growth Regeneration
CSF	Critical Success Factor
CSNP	Centralised Strategic Network Plan
DDM	Dynamic Dispatch Model The Dynamic Dispatch Model (DDM) is a comprehensive fully integrated power market model of DESNZ covering the GB power market over the medium to long term. The model enables analysis of electricity dispatch from GB power generators and investment decisions in generating capacity from 2010 through to 2050. UK TIMES | UCL ENERGY INSTITUTE MODELS - UCL – University College London
DECC	Department of Energy and Climate Change
DEFRA	Department for Environment, Food and Rural Affairs
DESNZ	Department for Energy Security and Net Zero
EINA	Energy Innovation Needs Assessment
ENC	Electricity Networks Commissioner
ENSTO-E	European Network of Transmission System Operators for Electricity; the European association for the cooperation of TSOs for electricity
ESO	Electricity System Operator; the electricity system operator for Great Britain (now NESO)
GB	Great Britain

Term	Definition
GDP	Gross Domestic Product; the market value of all the final goods and services produced in a specific period by a country
GHG	Greenhouse Gas
GREG	Government and Regulators Electrification Group
GVA	Gross Value Added; the value generated by any unit engaged in the production of goods and services
HPDR	Hydrogen Production Delivery Roadmap
HND	Holistic Network Design
HS2	High Speed 2; a high-speed railway line under construction in England
LCOE	Levelised Cost of Electricity
LODES	Longitudinal Employer-Household Dynamics; program that provides detailed local information on where people work and where jobs are located
LOLE	Loss of Load Expectation; the expected number of hours per year that a country's electricity production cannot meet its demand
MoU	Memorandum of Understanding; a nonbinding agreement that states each party's intentions to take action, conduct a business transaction or form a new partnership
MPI	Multi-Purpose Interconnector
NESO	National Energy System Operator; the name of the new independent, public corporation responsible for planning Britain's electricity and gas networks and operating the electricity system.
NGESO	National Grid Electricity System Operator
NPV	Net Present Value; a financial metric that seeks to capture the total value of an investment opportunity
NSEC	The North Seas Energy Cooperation (NSEC) (High level group since 2016)
NSI	Non-Standard Interconnector
NSIP	Nationally Significant Infrastructure Projects
OFGEM	Office of Gas and Electricity Markets
OFTO	Offshore Transmission Owners

Term	Definition
OHA	Offshore Hybrid Asset
ONDP	Offshore Network Development Plan (new plan according to Art. 14.2 of EU 2022/869), part of ENTSO-E's TYNDP)
Opex	Operating Expenditure
OSW	Offshore Wind
OTNR	Offshore Transmission Network Review
OWIC	Offshore Wind Industry Council
REMA	Review of Electricity Market Arrangements
ROC	Renewables Obligation Certificate; issues to operators of accredited renewable generating stations for the eligible renewable electricity they generate
TCA	Trade Cooperation Agreement
TNUoS	Transmission Network Use of System; these charges recover the cost of installing and maintaining the transmission system in England, Wales, Scotland and Offshore
TSO	Electricity Transmission System Operator
TTWA	Travel to Work Areas
TYNDP	Ten-Year Network Development Plan; generated and published by ENTSO-E every two years for electricity infrastructure and by ENTSOG for gas infrastructure

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