Hornsea Project Four: Additional Information

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Glossary

Term	Definition
Commitment	A term used interchangeably with mitigation and enhancement measures. The purpose of Commitments is to reduce and/or eliminate Likely Significant Effects (LSEs), in EIA terms. Primary (Design) or Tertiary (Inherent) are both embedded within the assessment at the relevant point in the EIA (e.g. at Scoping, Preliminary Environmental Information Report (PEIR) or ES). Secondary commitments are incorporated to reduce LSE to environmentally acceptable levels following initial assessment i.e. so that residual effects are acceptable.
Cumulative effects	The combined effect of Hornsea Four in combination with the effects from a number of different projects, on the same single receptor/resource. Cumulative impacts are those that result from changes caused by other past, present or reasonably foreseeable actions together with Hornsea Project Four.
Design Envelope	A description of the range of possible elements that make up the Hornsea Project Four design options under consideration, as set out in detail in the project description. This envelope is used to define Hornsea Project Four for Environmental Impact Assessment (EIA) purposes when the exact engineering parameters are not yet known. This is also often referred to as the "Rochdale Envelope" approach.
Development Consent Order (DCO)	An order made under the Planning Act 2008 granting development consent for one or more Nationally Significant Infrastructure Projects (NSIP).
Environmental Impact Assessment (EIA)	A statutory process by which certain planned projects must be assessed before a formal decision to proceed can be made. It involves the collection and consideration of environmental information, which fulfils the assessment requirements of the EIA Directive and EIA Regulations, including the publication of an Environmental Impact Assessment (EIA) Report.
Hornsea Project Four Offshore Wind Farm	The term covers all elements of the project (i.e. both the offshore and onshore). Hornsea Four infrastructure will include offshore generating stations (wind turbines), electrical export cables to landfall, and connection to the electricity transmission network. Hereafter referred to as Hornsea Four.
Landfall	The generic term applied to the entire landfall area between Mean Low Water Spring (MLWS) tide and the Transition Joint Bay (TJB) inclusive of all construction works, including the offshore and onshore ECC, intertidal working area and landfall compound. Where the offshore cables come ashore east of Fraisthorpe.
Maximum Design Scenario (MDS)	The maximum design parameters of each Hornsea Four asset (both on and offshore) considered to be a worst case for any given assessment.
Mitigation	A term used interchangeably with Commitment(s) by Hornsea Four. Mitigation measures (Commitments) are embedded within the assessment at the relevant point in the EIA (e.g. at Scoping, or PEIR or ES).
National Grid Electricity Transmission (NGET) substation	The grid connection location for Hornsea Four.
Onshore export cables	Cables connecting the landfall first to the onshore substation and then on to the NGET substation at Creyke Beck.
Onshore substation (OnSS)	Comprises a compound containing the electrical components for transforming the power supplied from Hornsea Project Four to 400 kV and to adjust the power quality and power factor, as required to meet the UK Grid Code for supply to the National Grid. If a HVDC

	system is used the OnSS will also house equipment to convert the power from HVDC to HVAC.
Order Limits	The limits within which Hornsea Project Four (the 'authorised project) may be carried out.
Orsted Hornsea Project Four Ltd.	The Applicant for the proposed Hornsea Project Four Offshore Wind Farm Development Consent Order (DCO).
Planning Inspectorate (PINS)	The agency responsible for operating the planning process for Nationally Significant Infrastructure Projects (NSIPs).
Trenchless Techniques	Also referred to as trenchless crossing techniques or trenchless methods. These techniques include Hydraulic Directional Drilling (HDD), thrust boring, auger boring, and pipe ramming, which allow ducts to be installed under an obstruction without breaking open the ground and digging a trench.

Acronyms

Term	Definition
CBRA	Cable Burial Risk Assessment
DCO	Development Consent Order
DBCB	Dogger Bank Creyke Beck
ECC	Export Cable Corridor
EIA	Environmental Impact Assessment
ES	Environmental Statement
HRA	Habitats Regulations Assessment
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
MBES	Multi-Beam Echo Sounder
MCZ	Marine Conservation Zone
MDS	Maximum Design Scenario
MLWS	Mean Low Water Springs
MMO	Marine Management Organisation
MPA	Marine Protected Area
PEIR	Preliminary Environmental Information Report
PINS	The Planning Inspectorate
PSA	Particle Size Analysis
SAC	Special Area of Conservation
SPA	Special Protection Area
SSS	Side-Scan Sonar
TCE	The Crown Estate
UKHO	UK Hydrographic Office

1 Executive Summary

1.1.1.1 Orsted Hornsea Project Four Limited (Hornsea Four) is seeking a Development Consent Order (DCO) for a GW-scale offshore wind farm with approximately 180 turbines, to be built out in the North Sea, approximately 120 km off the north Norfolk coast, in the late 2020s. The project is in possession of a Grid Connection Offer from National Grid Electricity System Operator (NGESO) for 2.6 GW of Transmission Entry Capacity.

1.1.1.2 This Statement of Need for offshore wind builds upon and updates the arguments made in the 2011 National Policy Statements (NPSs) and describes how and why the proposed project addresses all relevant aspects of established and emerging government Policy.

1.1.1.3 The case for need is built upon the contribution of the proposed development to the three important national policy aims of decarbonisation:

- Net-Zero and the importance of deploying zero-carbon generation assets at scale;
- Security of supply (geographically and technologically diverse supplies); and
- Affordability.

1.1.1.4 The case for need specifically includes a section on the effect of the 2020 COVID-19 pandemic on Great Britain's (GB) energy market and infrastructure investment, and the important role of energy infrastructure projects in fiscal recovery plans.

1.1.1.5 Chapter 3 provides a recap of the Policy framework established by the NPSs, and the arguments they include which support the need for significant new low-carbon electricity generation infrastructure in order to meet the UK's legal decarbonisation targets.

1.1.1.6 Chapter 4 sets out the legal requirement for decarbonisation in the United Kingdom (UK) and explains how that requirement has developed based on an increased need and urgency for decarbonisation in order to meet the UK's obligations under the Paris Agreement (2015). This chapter summarises the latest expert views on the urgency and depth of low-carbon investment required to deliver the UK's Net Zero legal obligations, including the National Infrastructure Strategy [1], the Committee on Climate Change (CCC) Sixth Carbon Budget [2], the Prime Minister's Ten Point Plan [31] and the Energy White Paper [18]: any new low-carbon power generation projects which can be delivered as soon as possible make valuable contributions to achieving net Zero, and many more projects than those currently under development will be required under all potential future scenarios of how to meet Net Zero.

1.1.1.7 Chapter 5 provides an up-to-date view of how decarbonisation in the UK has been achieved to date, through substantial reduction in coal-fired generation and the deployment of significant numbers of wind and solar installations, and explains why a number of assets as foreseen in previous carbon plans (and for which the NPS were largely written) have hitherto lagged behind Renewable Energy Sources (RES) in terms of their deployment.

1.1.1.8 Chapter 6 provides an overview of the effect of the COVID-19 pandemic on the UK energy market and provides industry views on demand and price recovery. UK and international governments are discussing the important role green investment would play in global recovery, and UK is signalling its ambition to "lead the way".

1.1.1.9 Chapter 7 confirms that future electricity demand will grow significantly through the decarbonisation-through-electrification of other industry sectors (the same reasons as those stated in the NPS), and therefore that significant new low-carbon electricity generation developments, as discussed in Chapter 8, are required to meet that demand and deliver decarbonisation.

1.1.1.10 Chapter 9 explains the contribution of offshore wind generation to security of supply, both from an availability and a system operation perspective, and concludes that Hornsea Four, if approved, would contribute to an adequate and dependable GB generation mix.

1.1.1.11 Chapter 10 provides an analysis of the economic viability of large-scale off-shore wind, as a future contributor to a low-carbon GB electricity supply system, in comparison to alternate technologies.

1.1.1.12 Chapter 11 provides an overview of the role of integration technologies in the future Net-Zero energy system, in particular the cross-vector nature of the leading viable pathways to a Net-Zero future and the importance of integrating low-carbon generation at scale, with Energy Balancing Infrastructure (EBI) technologies, such as hydrogen and electricity storage.

1.1.1.13 Chapter 12 concludes that significant capacities of low-carbon offshore wind generation is needed in the UK, and that integration technologies will also play an essential part in delivering Net Zero for the UK. Therefore, developing Hornsea Four as planned will help meet government objectives of delivering sustainable development to enable decarbonisation, ensuring our energy supply is secure, low-carbon and provides benefits to GB consumers.

1.1.1.14 It is the view of the author of this report that if a significant capacity of offshore wind generation is not built out to a scale comparable with that in the projections provided by NGESO and others, then the UK will be highly unlikely to continue to reduce its carbon emissions over the coming decade, and ultimately fail to meet its legally binding decarbonisation targets. Hornsea Four will provide a significant and vital contribution towards both meeting the national need demonstrated by the Overarching National Policy Statement for Energy (EN-1) [3] and towards the delivery of renewable energy.

2 Introduction

2.1.1.1 Orsted Hornsea Project Four Limited (Hornsea Four) is seeking a Development Consent Order (DCO) for a GW-scale offshore wind farm with approximately 180 turbines, to be built out in the North Sea, approximately 120 km off the north Norfolk coast, in the late 2020s. Hornsea Project One and Hornsea Project Two have both received planning consent and are either commercially operational or under construction. Hornsea Project Three was granted a Development Consent Order on 31st December 2020. Orsted is now developing Hornsea Four to the west of these. Hornsea Four is in possession of a Grid Connection Offer from NGESO for 2.6 GW of Transmission Entry Capacity. This Statement of Need supports the DCO application submitted by Hornsea Four.

2.1.1.2 Offshore wind projects fall under the Nationally Significant Infrastructure Planning (NSIP) regime and the need for such projects is covered by the National Policy Statements (NPS) EN-1 [3] and EN-3 [4]. The current NPS were published in 2011, and many of the arguments made within them can be refreshed, in order to take into account current legislation, regulation, policy, technology and market developments. This Statement of Need for offshore wind, builds upon and updates the arguments made in the NPS documents, and describes how and why the proposed project addresses all relevant aspects of established and emerging government policy.

2.1.1.3 The case for need is built upon the contribution of the proposed development to the three important national policy aims of decarbonisation (Net-Zero and the importance of developing at-scale zero-carbon generation assets); security of supply (geographically and technologically diverse supplies); and affordability. This Statement of Need includes a description of how decarbonisation has so far been achieved in GB, and where further decarbonisation is required to meet the Net-Zero legal requirements. The need to decarbonise further underpins the need for at-scale, urgent delivery of consentable and affordable projects which make best use of GB's natural low-carbon energy resources. The nuances of the fundamental arguments made in the 2011 NPSs have progressively shifted over recent years, and government, industry and international attention in the area of decarbonisation continues to grow. This is particularly relevant given the central role that the Government has placed on a 'Green Recovery' from the 2020 Covid-19 pandemic, as laid out in the Prime Minister's 10 Point Plan for a Green Industrial Revolution in November 2020 [31], which indicated that investment in green infrastructure, and offshore wind in particular, is a central part of the Government's economic recovery plan.

2.1.1.4 This Statement has been prepared by Si Gillett, M.A.(Oxon), M.Sc.(Dist) and updates the case set out in the 2011 NPS for why offshore wind is an important generation technology to include within the future GB generation mix. This Statement of Need extends the case made in the NPSs, and predominantly calls on established and emerging primary analysis and opinion by respected third parties, to support the case that Hornsea Four will help GB meet its legally binding carbon emissions targets, while enhancing national security of supply, and at a cost which, in relation to other electricity generation infrastructure developments, provides value for money for GB end-use consumers.

2.1.1.5 The conclusion reached is that significant capacities of low-carbon offshore wind generation is needed in the UK, and that developing Hornsea Four as planned, will help meet government objectives of delivering sustainable development to enable decarbonisation, ensuring our energy supply is secure, low-carbon and provides benefits to GB consumers.

3 The National Policy Statements

3.1 Establishing the basis provided by the existing NPSs

3.1.1.1 The NPSs were established against obligations made as part of the Climate Change Act 2008 (CCA2008) – see Section 4.1 following. The Overarching National Policy Statement for Energy (NPS EN-1) [3] sets out national policy for energy infrastructure in the UK. It has effect, in combination with NPS EN-3 (for renewable energy infrastructure) [4] and NPS EN-5 (for electricity networks) [17], on recommendations made by the appointed Examining Authority (ExA) to the SoS for BEIS on applications for energy developments that fall within the scope of the NPSs [3, Para 1.1.1]. These NPSs, when combined with the relevant technology-specific energy NPS, provide the primary basis for decisions by the SoS. The NPSs set out a case for the need and urgency for new energy infrastructure [3, Paras 3.3.1 & 3.3.15]. The urgency of the need requires actions to be taken in the near-term in order for that need to be met and therefore the near-term need for the Scheme is demonstrated by the urgent need for new energy infrastructure as set out in NPS EN-1. Further, the NPSs set out a case for new energy infrastructure to be consented and built with the objective of supporting the government's policies on sustainable development, by:

- Mitigating and adapting to climate change; and
- Contributing to a secure, diverse and affordable energy supply. [4, Para 1.3.1].

3.1.1.2 The NPS for renewable energy infrastructure cover those technologies which, at the time of publication in 2011, were technically viable at generation capacities of over 50 MW onshore and 100 MW offshore. Critically, this includes offshore wind, and as such the need for this technology is fully covered by the NPSs. By virtue of its intended generating capacity, the NPSs are relevant and applicable to Hornsea Four's application. This document therefore complements and refreshes the analysis of needs as contained in the NPS documents to offshore wind technology. It parallels the existing arguments in the NPSs to demonstrate, offshore wind can and will deliver benefits for the UK. These benefits manifest in terms of the technology's contribution to the UK's legal decarbonisation targets; improvement in security of overall electricity supply; and improvement in the affordability of electricity for consumers.

3.1.1.3 The arguments made in the NPSs in 2011 have shifted as a result of a growing urgency (informed by developing scientific opinion) to reduce carbon emissions globally and locally; and the progress made by other low-carbon technologies and initiatives which were expected to deliver a low-carbon electricity system but are currently falling behind in delivering against that expectation.

3.1.1.4 The government has determined that the NPSs should be reviewed and in its December 2020 Energy White Paper [18], government signalled a review of the existing National Policy Statements, issuing draft versions of NPS EN-1 and EN-3 for consultation on 6th September 2021 [100, 101]. While the Draft NPS EN-1 confirms that the "Secretary of State has decided that for any application accepted for examination before designation of the 2021 amendments, the 2011 suite of NPSs should have effect in accordance with the terms of those NPS." [100, Para 1.6.2] the same document also states that "any emerging draft NPSs (or those designated but not having effect) are potentially capable of being important and relevant considerations in the decision-making process" [100, Para 1.6.3]. Section 3.3 therefore contains a synthesis of the 2021 Draft National Policy Statement EN-1 and shows that the demonstration of need for Hornsea Four set out in this Statement of Need is consistent with the updated arguments contained within the revised NPSs.

3.1.1.5 The Energy White Paper showed that the need for the energy infrastructure set out in energy NPS remains, except in the case of coal-fired generation. While the drafts are under consultation, the current suite of NPS remain relevant government policy and have effect for the purposes of the Planning Act 2008. They will, therefore, continue to provide a proper basis on which the Planning Inspectorate can examine, and the Secretary of State can make decisions on, applications for development consent. Nothing in the White Paper should be construed as setting a limit on the number of development consent orders which may be granted for any type of generating infrastructure set out in the energy NPSs. [18, p55]

3.1.1.6 This Statement of Need therefore extends the analysis contained in the NPS documents to cover low-carbon electricity generation against today's climate, security of supply and cost of generation. It develops the arguments made within EN-3 for large offshore wind technology, and extends them to demonstrate: firstly, that there is now even more need for this technology in GB; secondly, that this technology is now even more technically and economically feasible than it was in 2011; thirdly, that large-scale offshore wind can and will bring benefits for GB; and fourthly that integration technologies will play an essential role in full decarbonisation of the whole energy system, enhancing the benefits brought by low-carbon generation to GB. These benefits manifest in terms of material contribution to legal decarbonisation targets; enhancement of security of supply; and managing the affordability of electricity for GB consumers.

3.1.1.7 The NPSs set out, for England and Wales, the national case for NSIP energy projects, and establish the need for certain types of infrastructure, as well as identifying potential key issues that should be considered by the decision maker. S104 of the Planning Act (2008) makes clear that where an NPS exists relating to the development type applied for, the SoS must have regard to it. The NPSs provide specific policy in relation to offshore wind development, and the policies set out in NPS EN-1, 3 and 5 therefore apply and being unquestionably 'important and relevant' therefore should afford significant weight in any planning assessment process. In light of the treatment of relevant NPSs in the consideration of previous DCO applications, the urgent national need for energy generating stations set out in both NPS EN-1 and EN-3 is of great significance to the determination of Hornsea Four. The test as relevant to Hornsea Four therefore becomes whether the need for the development at the national level is outweighed by other material considerations.

3.1.1.8 Policies within NPSs EN-1 (Energy), EN-3 (Renewable Energy Infrastructure) and EN-5 (Electricity Networks) are important and relevant to this proposal. The policies which are of particular relevance and importance to this examination are set out in Section 3.2.

3.2 A synthesis of the 2011 National Policy Statements EN-1 and EN-3

3.2.1.1 At the time the NPSs were published, scientific opinion was that, to avoid the most dangerous impacts of climate change, the increase in average global temperatures must be kept to no more than 2 °C. Global emissions must therefore start falling as a matter of urgency. [3, Para 2.2.8]

3.2.1.2 The energy NPSs were intended to speed up the transition to a low carbon economy and help the UK to realise its climate change commitments sooner than would a continuation under the current planning system [3, Para 11.7.2]. They recognise that moving to a secure, low carbon energy system to enable the UK to meet its legally binding target to cut greenhouse gas emissions by at least 80% by 2050, compared to 1990 levels, is challenging, but achievable.

3.2.1.3 This would require major investment in new technologies to electrify heating, industry and transport, and cleaner power generation [3, Para 2.2.1]. Under some 2050 pathways, electricity generation would need to be virtually emission-free, because emissions from other sectors were expected still to persist [3, Para 2.2.6]. Consequentially, the need to electrify large parts of the industrial and domestic heat and transport sectors, either directly or through the use of intermediary energy vectors, will significantly increase electricity demand by 2050. [3, Para 2.2.22]

3.2.1.4 The UK chose to largely decarbonise its power sector by adopting low carbon sources quickly, and identified offshore wind as a critical low-carbon and proven fuel source. [3, Para 3.3.5]

3.2.1.5 The NPSs conclude that the UK needs sufficient electricity capacity from a diverse mix of technologies and fuels [3, Para 2.2.20], and therefore the UK also needs all the types of energy infrastructure covered by the NPSs in order to achieve energy security at the same time as dramatically reducing greenhouse gas emissions [3, Para 3.1.1]. Chapter 3 of this Statement of Need describes the progress made in decarbonisation in the UK to date, and demonstrates that many of the foreseen technologies covered by the NPSs, due either to technological reasons or project development timescales, will not be sufficient to contribute significantly to decarbonisation through the important 2020s. Thus applications for development consent for the types of infrastructure covered by the energy NPSs should be assessed on the basis that the government has demonstrated that there is a need for those types of infrastructure and that the scale and urgency of that need is as described within EN-1 Part 3. Substantial weight may therefore be given to the contribution which projects would make towards satisfying this need when considering applications for development consent under the Planning Act 2008 [3, Paras 3.1.3, 3.1.4]. The economic feasibility of harvesting and sufficient available natural resource will be an important driver for proposed locations of renewable energy projects. [4, Para 2.6.57]

3.2.1.6 To hit the target of UK commitments to largely decarbonise the power sector by 2030, the NPSs conclude that it is necessary to bring forward new renewable electricity generating projects as soon as possible. The need for new renewable electricity generation projects is therefore urgent.

3.2.1.7 Offshore wind farms are expected to make up a significant proportion of the UK's renewable energy generating capacity up to 2020 and towards 2050 [4, Para 2.6.1], further detail is provided in Section 8.4

3.3 A synthesis of the 2021 Draft National Policy Statement EN-1

3.3.1.1 The structure of the NPS suite has not changed in the latest draft documents. Draft NPS EN-1 sets out the Government's policy for delivery of major energy infrastructure, and EN-3 covers both onshore and offshore renewable electricity generation. However given the increasing urgency of action required to combat climate change, the draft NPSs are recognised as being "transformational in enabling England and Wales to transition to a low carbon economy and thus help to realise UK climate change commitments sooner than continuation under the current planning system." [100, Para 1.7.4]

3.3.1.2 The fundamental need for the large-scale infrastructure which draft NPS EN-1 considers remains the legal commitment to decarbonisation to Net Zero by 2050 in order to hold the increase in global average temperature due to climate change, to well below 2 degrees above pre-industrial levels, as described in Chapter 4 of this Statement of Need. The NPS states that:

> *Using electrification to reduce emissions in large parts of transport, heating and industry could lead to more than half of final energy demand being met by electricity in 2050, up from 17 per cent in 2019, representing a doubling in demand for electricity. Low carbon hydrogen is also likely to play an increasingly significant role.* [100, Para 2.3.6]

3.3.1.3 Government direction is to develop an integrated energy system which relies on low-carbon electricity generation for a significant proportion of its supply. As a consequence:

> *Demand for electricity is likely to increase significantly over the coming years and could more than double by 2050 as large parts of transport, heating and industry decarbonise by switching from fossil fuels to low carbon electricity. The Impact Assessment for CB6 shows an illustrative range of 465-515TWh in 2035 and 610-800TWh in 2050.* [100. Para 3.3.3]

3.3.1.4 This Statement of Need comes to the same conclusion in Chapter 7, and also recognises that low-carbon generation is already cheaper than fossil fuel generation on a both marginal cost basis and Lifetime Cost of Electricity basis (see Chapter 10).

3.3.1.5 Section 3.3 of draft NPS EN-1 explains that large capacities of low-carbon generation will be required to ensure that there is sufficient electricity to meet increased demand, to replace output from retiring plants and to ensure there is sufficient margin in our supply to accommodate unexpectedly high demand and mitigate risks such as unexpected plant closures and extreme weather events. This Statement of Need parallels the arguments made in draft NPS EN-1 within Chapters 8 and 9.

3.3.1.6 Draft NPS EN-1 articulates the prudence of planning infrastructure development of a conservative basis, including where the use of hydrogen is limited [100, Para 3.3.11] and, like this Statement of Need, concludes that there is an urgent need for new electricity generating capacity to meet our energy objectives. Further, although "a secure, reliable, affordable, net zero consistent system in 2050 is likely to be composed predominantly of wind and solar." [100, Para 3.3.31] Both this Statement of Need and draft NPS EN-1 conclude that all low-carbon generating technologies are urgently needed to meet the government's energy objectives by:

- Providing security of supply;
- Providing an affordable, reliable system (through the deployment of technologies with complementary characteristics); and
- Ensuring the system is net zero consistent.

3.3.1.7 In noting the crucial national benefits of increased system robustness through new electricity network infrastructure projects, draft NPS EN-1 also recognises the particular strategic importance this decade of the role of offshore wind in the UK's generation mix. Offshore wind "presents the challenge of connecting a large volume of generation located beyond the periphery of the existing transmission network" and therefore sets an "an expectation that there will be a need for substantially more installed offshore capacity … to achieve net-zero by 2050" [100, Paras 3.3.49-3.3.50]. Draft NPS EN-1 goes on to provide that:

> *The Secretary of State should consider that the need for a new connection or network reinforcement has been demonstrated if the proposed development represents an efficient and economical means of: connecting a new generating station to the network; reinforcing the network to accommodate such connections; or reinforcing the network to ensure that it is sufficiently resilient and capacious (per any performance standards set by Ofgem) to reliably supply present and/or anticipated future levels of demand.* [100, Para 3.3.55]

3.3.1.8 Much of the required electricity infrastructure is anticipated to be required to support continued development of large-scale capacity at the transmission level, "because connection of large-scale, centralised electricity generating facilities via a high voltage transmission system enables the pooling of both generation and demand, which in turn offers a number of economic and other benefits, such as more efficient bulk transfer of power and enabling surplus generation capacity in one area to be used to cover shortfalls elsewhere." [100, Para 3.3.14]

> *Government does not believe [decentralised and community energy systems] will replace the need for new large-scale electricity infrastructure to meet our energy objectives" although it is recognised that they make an important contribution to meeting national targets on reducing carbon emissions and increasing energy security.* [100, Para 3.3.13]

3.3.1.9 In relation to integration technologies, Draft NPS EN-1 states that:

> *New generating plants can deliver a low carbon and reliable system, but we need the increased flexibility provided by new storage and interconnectors (as well as demand side response, discussed above) to reduce costs in support of an affordable supply. Storage and interconnection can provide flexibility, meaning that less of the output of plant is wasted as it can either be stored or exported when there is excess production.* [100, Paras 3.3.16&17]

3.3.1.10 Draft NPS EN-1 draft goes on to explain that storage is needed to reduce the costs of the electricity system and increase reliability by storing surplus electricity in times of over-supply, to provide electricity when demand is higher. The local and national services which can be provided by storage are also referenced in EN-1, being "peak shaving" constraint management and the provision of a range of balancing services. [100, Para 3.3.25]. The role of "low-carbon hydrogen" is also signalled as likely growing in significance in the future GB energy system, and therefore supports the need for the infrastructure required to generate low-carbon power, and produce, store and transport hydrogen to where it is needed [100, Paras 2.3.5-2.3.7]. This Statement of Need provides additional and complimentary arguments for the need for electricity storage and hydrogen in Chapter 11.

4 The UK has a legal commitment to decarbonise

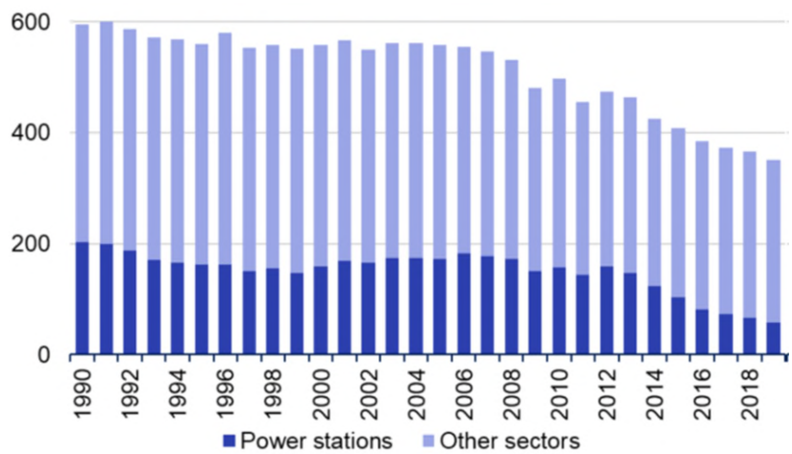
This chapter sets out the obligations of the Climate Change Act 2008, against which the NSPs (2011) were established. It then outlines the UK's 2019 legally binding commitment to achieving 'Net-Zero' carbon emissions by 2050, against which the need for future electricity generation developments should be assessed.

4.1 Climate Change Act 2008

4.1.1.1 The government, through Climate Change Act 2008 (CCA2008), made the UK[1] the first country in the world to set legally binding carbon budgets, aiming to cut emissions (versus 1990 baselines) by 34% by 2020 and at least 80% by 2050, "through investment in energy efficiency and clean energy technologies such as renewables, nuclear and carbon capture and storage." [16, Five Point Plan]

4.1.1.2 CCA2008 is underpinned by further legislation and policy measures. Many of these have been consolidated in the UK Low Carbon Transition Plan [16], and UK Clean Growth Strategy (2017) [19]. A statutory body, the Committee on Climate Change (CCC), was also created by CCA2008, to advise the United Kingdom and devolved governments and Parliaments on tackling and preparing for climate change, and to advise on setting carbon budgets. The CCC report regularly to the Parliaments and Assemblies on the progress made in reducing greenhouse gas emissions. The CCC report regularly to the Parliaments and Assemblies on the progress made in reducing greenhouse gas emissions. The UK government has set five-yearly carbon budgets which currently run until 2037, the process for setting the sixth carbon budget having concluded in April 2021. The UK has met its first and second carbon budgets and is on track to outperform the third (2018 to 2022) – partly attributable to effective policy, but also attributed to changes in the applicable Emissions Trading Scheme(s) and the impact of COVID-19 on emissions [2, p435].

Figure 4-1: UK greenhouse gas emissions, 1990 – 2019 (provisional). [5, p9]



4.1.1.3 Up to 2019, the UK has made progress with its carbon reduction obligations, as shown in

[1] The commitment to decarbonise extends across the United Kingdom of Great Britain and Northern Ireland. Northern Ireland is interconnected with the mainland power system through interconnectors, but is operated under a different electricity market framework. Therefore, hereinafter we refer to GB in relation to electricity generation and transmission, and the UK, to refer to the nation which has legally committed itself to Net-Zero carbon emissions by 2050.

Figure 2.1, through significant reductions in the power, industry and waste sectors. CCA2008 obligations translate to a total emissions target of ~550 MtCO2e in 2020, and ~ 165 MtCO2 e in 2050. The main driver of UK carbon reduction to date has been the power generation sector. Overall carbon intensity from power generation has fallen significantly in recent years, with (virtually) carbon-free generation (wind, solar, hydro, bioenergy, and nuclear) accounting for around 62% of electricity generation in 2020 [94]. CCA2008 committed the UK to sourcing 15% of its total energy (across the sectors of transport, electricity and heat) from renewable sources by 2020 and new projects were expected to need to continue to come forward urgently to ensure that this target was met. Government projections made in 2011 suggested that by 2020 about 30% or more of GB electricity generation – both centralised and small-scale – could come from renewable sources, compared to 6.7% in 2009 [3, Para. 3.4.1].

4.1.1.4 All industry sectors have important roles to play in decarbonisation, but so far carbon reductions outside of power, industry and waste have been small, as shown in Figure 2.1. Electrification of non-power sectors is therefore an important part of the realisation of overall carbon emission reductions. Indeed:

> *Moving to a secure, low carbon energy system is challenging, but achievable. It requires major investment in new technologies to renovate our buildings, the electrification of much of our heating, industry and transport, prioritisation of sustainable bioenergy and cleaner power generation.* [3, Para 2.1.1].

4.1.1.5 However, the UK context for the need for greater capacities of low-carbon UK generation to come forward with pace, has continued to develop since 2018. In October 2018, following the adoption by the UN Framework Convention on Climate Change of the Paris Agreement, the Intergovernmental Panel on Climate Change (IPCC) published a "Special Report on the impacts of global warming of 1.5°C above pre-industrial levels". This report concluded that human-induced warming had already reached approximately 1°C above pre-industrial levels, and that without a significant and rapid decline in emissions across all sectors, global warming would not be likely to be contained, and therefore more urgent international action is required. The ambition against which CCA2008 was established has been extended, and the targets for carbon emissions reduction have tightened.

4.2 Enhancements of existing UK government policy on climate change: Net-Zero

4.2.1.1 In response to the IPCC report, in May 2019, the CCC published "Net-Zero: The UK's contribution to stopping global warming." [21]. This report recommended that government extend the ambition of CCA2008 past the delivery of net UK greenhouse gas savings by 80% from 1990 levels, by 2050. The CCC recommended that "The UK should set and vigorously pursue an ambitious target to reduce greenhouse gas emissions (GHGs) to 'Net-Zero' by 2050, ending the UK's contribution to global warming within 30 years." The CCC believe that this recommendation is "necessary [against the context of international scientific studies], feasible [in that the technology to deliver the recommendation already exists] and cost-effective", reporting that "falling costs for key technologies mean that … renewable power (e.g. solar, wind) is now as cheap as or cheaper than fossil fuels". Importantly, the CCC recommendation identifies a need for low-carbon infrastructure development which is consistent with the need case set out in NPS EN-1, but points to an increased urgency for action.

4.2.1.2 In March 2019 government announced its ambition to deliver at least 30 GW of offshore wind by 2030, as part of the Offshore Wind Sector Deal [22]. The Sector Deal reinforced the aims of the UK's Industrial Strategy and Clean Growth Strategy, which seeks to maximise the advantages for UK industry from the global shift to clean growth, and in particular: 'The deal will drive the transformation of offshore wind generation, making it an integral part of a low-cost, low-carbon, flexible grid system.' The deal paved the way for further ambition in the offshore wind sector later in 2019.

4.2.1.3 In June 2019, the government announced the laying of a statutory instrument in Parliament, which amended CCA2008, in order to implement the CCC's recommendation into law. The UK thus became the first major economy to pass laws to end its contribution to global warming by 2050. In the same month, the CCC also reported to Parliament that 'UK action to curb greenhouse gas emissions is lagging behind what is needed to meet legally-binding emissions targets' [23]. Despite having met its first and second carbon budgets, and being on track to outperform its third (2018 to 2022), the UK, is not on track to meet the fourth (2023-2027) or fifth carbon budget (2028-2032). Recognising the need for progress in decarbonisation to continue, the CCCs recommendations for a sixth carbon budget, running from 2033-2037, include measures which, when delivered, will result in a 78% reduction in UK territorial emissions between 1990 and 2035, in effect, bringing forwards the UK's previous 80% target by nearly 15 years [2, p5].

4.2.1.4 Figure 4-1 illustrates the reduction in carbon emissions from electricity generation which has been achieved since 1990. Despite this reduction, the CCC's position is that extending the ambition of CCA2008 is not credible unless decarbonisation progresses with far greater urgency than currently exists. The CCC's June 2020 report to parliament stated that:

> *To reach the UK's new Net Zero target emissions will need to fall, on average, by around 14 MtCO2 e every year, equivalent to 3% of emissions in 2019. As the existing carbon budgets were set on a cost-effective path to achieving an 80% reduction in UK greenhouse gas emissions by 2050, a more ambitious long-term target is likely to require outperformance of the carbon budgets legislated to date*. [26, pp52-53].

4.2.1.5 Consistent with the NPS, the UK's pathway to a successful 2050 carbon budget must involve wider transitions outside of the power generation sector: decarbonisation of transport, industry, agriculture and the home, and utilisation of alternate energy vectors to enable the decarbonisation of traditionally hard-to-reach sectors remains required to reduce non-power sector emissions. The CCC agree that decarbonisation progress must occur not only within the electricity generation sector, but also in other sectors which use energy, including low-carbon heating systems in the built environment, and the electrification of transport, with most sectors needing to reduce emissions to close to zero by 2050 for the Net-Zero target to be achieved. The CCC anticipate a future of 'Extensive electrification, particularly of transport and heating, supported by a major expansion of renewable and other low-carbon power generation.' See Chapter 7 for a more detailed analysis. Continuing as we are is, simply put, not enough. The increased electrification of primary energy use will double-down on the requirement to reduce carbon emissions from electricity generation even further than that which has already been achieved. Therefore, in order to deliver carbon savings, it is vitally important to ensure that GB is capable of meeting an increased demand for electricity in a secure way, with a significantly lower carbon intensity even than current levels. The decarbonisation of GB's electricity generation assets is therefore of vital importance in meeting the UK's legal obligations on carbon emissions.

4.2.1.6 The Energy Systems Catapult (ESC) was set up to accelerate the transformation of the UK's energy system and ensure UK businesses and consumers capture the opportunities of clean growth. The ESC is an independent, not-for-profit centre of excellence that bridges the gap between industry, government, academia and research. In March 2020, the ESC's 'Innovating to Net Zero' report observed that:

> *Net Zero narrows the set of viable pathways for the future energy system. Where an 80% target allowed considerable variation in relative effort across the economy, with some fossil fuels still permissible in most sectors, Net Zero leaves little slack.* [7, p5]

4.2.1.7 ESC analysis [7, pp23, 27] anticipates that the decarbonisation of other sectors will require at least double today's electricity demand by 2050, all of which must come from zero-carbon sources. This, coupled with NGESO's own forecasts of the UK's requirement for electricity generated from low-carbon sources in the UK, leads to the conclusion that, in order for the UK to achieve Net-Zero, all available low-carbon resource and infrastructure developments must be brought forward at pace: the power generation sector must both increase in capacity and reduce in carbon intensity on an unprecedented scale.

4.3 UK demonstrating leadership on climate action

4.3.1.1 Government policy on climate change does not stop at our national borders, indeed since 2010, government has included within its policy actions, 'driving ambitious action on climate change at home and abroad' [3, Para 2.2.3]. In this regard, the CCC states:

> *Whether the world achieves the long-term temperature goal of the Paris Agreement will depend on the actions of other countries alongside the UK. A large-scale shift in investment towards low-carbon technologies is needed and emissions need to stop rising and to start reducing rapidly. Falling costs for key technologies mean that the future will be different from the past: renewable power (e.g. solar, wind) is now as cheap as or cheaper than fossil fuels in most parts of the world.* [25, pp83-84]

> *More rapid electrification must be accompanied with greater build rates of low-carbon generation capacity, accompanied by measures to enhance the flexibility of the electricity system to accommodate high proportions of inflexible generation (e.g. wind). The Energy White Paper and Draft NPS EN-1 both anticipate the need for a quadrupling of low-carbon power generation by 2050. While key options like offshore wind look increasingly like they can be deployed without subsidy, this does not mean they will reach the necessary scale without continued government intervention (e.g. continued auctioning of long-term contracts with subsidy-free reserve prices)* [25, p178]

4.3.1.2 And further, sets out an ambitious course for the UK to lead, internationally, in climate change mitigations and actions:

The UK has the strongest record of emissions reduction in the G20 over the last decade, and over a longer period back to 1990. [24, p13]

UK domestic climate ambition can be the basis for UK international leadership in 2021, in the Presidency of the delayed UN climate summit in Glasgow (COP26) and in the G7 Presidency. [24, p16]

4.3.1.3 Within supplementary documents to the Queens Speech, December 2019 [26, p116], government committed to 'increase [their] ambition on offshore wind to 40 GW by 2030 [providing it remained value for money], and enable new floating turbines'.

4.3.1.4 At the end of June 2020, the Prime Minister set out his vision that the UK would lead in markets and technologies. He committed to backing the vision of the UK becoming a global leader in developing batteries, and said that the UK would lead in long-term solutions to global warming such as solar, wind, nuclear, hydrogen and carbon capture and storage. [29]

4.3.1.5 In July 2020, government made commitments to support the transition from natural gas to clean hydrogen power, and to scale up carbon capture and storage, by providing £350M funding for a "green recovery supercharge." Such an endeavour is necessary for the decarbonisation of heavy industry, construction, space and transport sectors. This funding has been announced in support of meeting the Prime Minister's goal of leading the most ambitious environmental programme worldwide [30].

4.3.1.6 In August 2020, government announced funding for a number of green infrastructure development and innovation projects [31]. The South West Floating Offshore Wind Accelerator received funding to fast-track the building of large-scale floating offshore wind farms in the Celtic Sea from 2025 onwards. The funding is further evidence of government's continued backing of the sector and its support for organisations to make decisive contributions to GB's 2030 offshore wind capacity target of 40 GW and to lead international development in this field.

4.3.1.7 In August 2020, the National Infrastructure Commission (NIC) issued a report stating that:

The latest analysis for the Commission suggests that 65 per cent of Britain's electricity could be delivered from renewables by 2030 with no material change in cost when compared to the Commission's previous recommendation to deliver 50 per cent renewables. [32, p5]

4.3.1.8 Importantly, the CCC recognise offshore wind as the most important technology for GB low-carbon generation: a position consistent with that of the Applicant. The CCC make recommendations for BEIS to "deliver plans to decarbonise the power system to reach an emissions intensity of 50 gCO_2/kWh by 2030, with at least 40 GW of offshore wind and a role for onshore wind and large-scale solar power, with a clear timetable of regular auctions" [24, Table 4].

4.3.1.9 In November 2020, the Prime Minister published his Ten Point Plan to 'create, support and protect hundreds of thousands of green jobs, whilst making strides towards net zero by 2050'. The plan included, as its first point, a confirmation of government's commitment to an increased capacity of offshore wind as contained in the previous year's Queen's Speech and described a target to 'produce enough offshore wind to power every home in the UK, quadrupling how much it produces to 40 gigawatts by 2030' [31].

4.3.1.10 Against this context, the urgent need for large capacities of low-carbon generation is clear, and momentum is building from varied independent experts, in support of GB's drive capability and capacity to lead the world in decarbonisation. The CCC write:

> *The signs point to a propitious moment for global climate ambition in Glasgow next year. But our international leadership, in the Presidency of COP26 and of the G7, must begin at home. Our influence in the wider world rests ultimately on strong domestic ambition. [2, p6]*

4.3.1.11 And government seem to have accepted this advice:

> *The actions we take as a result of this white paper, as part of our wider climate agenda, are intended to show leadership and vision and demonstrate to our partners around the world that now is the time to take the bold steps to tackle climate change. The UK is leading from the front in the transition to clean energy, while ensuring that we leave no one behind as we build back greener.* [18, p2]

4.3.1.12 The chronology of UK policy development for low carbon generation, and the development of offshore wind capacity, shows that the need for offshore wind is increasing. Indeed the CCC's Balanced Pathway scenario updated to support their recommendations for a Sixth Carbon Budget shows offshore wind making the largest contribution to the supply of electricity, with generating capacities "reaching the Government's goal of 40 GW in 2030, on a path to 65-125 GW by 2050" [2, p25]. Within this context, Hornsea Four will be a necessary part of the future generation mix, and as such will make a valuable contribution in the direction of adopted UK government policy and the achievement of world-leading decarbonisation commitments.

5 Progress against the Low Carbon Transition Plan

5.1 Setting the scene on decarbonisation

> *The UK needs to wean itself off such a high carbon energy mix to reduce greenhouse gas emissions.* [3, Para 2.2.6]
>
> *The Overarching National Policy Statement on Energy EN-1 sets out how the energy sector can help deliver the government's climate change objectives by clearly setting out the need for new low carbon energy infrastructure to contribute to climate change mitigation.* [3, Para 2.2.11]
>
> *It is for industry to propose new energy infrastructure projects within the strategic framework set by government.* [3, Para 3.1.2]

5.1.1.1 In 2011, approximately 75% of GB's electricity came from carbon-based fuels; and contributed over a third of UK greenhouse gas emissions. Since then, carbon emissions from electricity have reduced, but mainly through measures other than those as expected in the Low Carbon Transition Plan.

5.2 Progress to date in achieving emission reductions in GB

5.2.1.1 Figure 4-1 shows the trend in reductions in carbon emissions in the UK, including from power generation, since 1990. Power sector reductions have been achieved through many initiatives and circumstances, including:

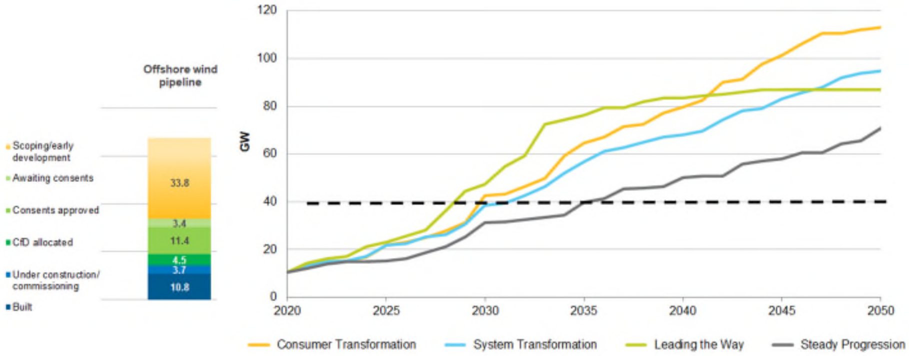
- Electricity volumes generated from coal and gas fired plants has reduced. The Large Combustible Plant Directive (aiming to improve air quality but also having significant carbon reduction benefits) required the clean up or time-limited operation of coal-fired power generation prior to 2016. Between 2012 and 2015, at least 11.5 GW of coal plant decommissioned as a result of the Directive. Further, in late 2017, government announced a commitment to a programme that will phase coal out of all electricity generation by 2025. National carbon pricing ensures that coal assets have unfavourable marginal costs (see Section 10.2) and are therefore dispatched only when absolutely necessary. In June 2020, Britain ended a record run of not generating any electricity from coal for 1,630 consecutive hours – the longest period since the 1880s, and less than 400 GWh has been generated from coal in the period April – September 2020. In 2019, many asset operators announced the closure of their coal generation assets. Just one coal station will remain commercially operational beyond 2021 with a generation capacity of 2.0 GW [Author Analysis].
- GB's second generation nuclear fleet (9 GW) has continued to operate significantly past its original decommissioning dates. Despite availability issues at three of the older stations, nuclear provided 16% of electricity demand in 2020 with low carbon emissions [94], however the decommissioning of existing plants commenced in 2021. Advances in new nuclear plants to replace the existing fleet have been slower than was originally envisioned (see Section 5.4).
- Low carbon variable generation, predominantly wind and solar, has been deployed to the GB grid more quickly and more widely than originally projected.

5.2.1.2 The GB energy market is complex with long-term price uncertainty. Within it, multiple players are developing assets in response to market signals rather than as a result of a centrally coordinated asset development program [32, p80]. Long-term electricity price uncertainty does not provide sufficient confidence for private investment into in high-capital, large generation assets. Therefore very few are being progressed without some mechanism to manage forward revenue risk.

5.2.1.3 Consequently, investors have increasingly been attracted to technologies (such as renewables) which are eligible for government-backed support programmes (such as the Contract for Difference), which address market risk. Interest from investors and developers in these technologies has driven technical development and competition on cost.

5.2.1.4 In response, government has repeatedly confirmed that both solar and onshore wind have now been readmitted to the CfD mechanism, the next Allocation Round (AR4) is scheduled for 2021. Details of the structure of AR4 were published in late 2020, indicating an increase in the pot sizes available for both new and established technologies, a clear sign for low-carbon power generation investment to come forwards without delay. In 2021, government confirmed that £200M would be allocated to the offshore wind CfD pot[2].

Figure 5-1: Illustration of potential offshore wind projects by FES scenario [94, Figure SV.28]



5.2.1.5 Conventional (thermal, dispatchable) plants in GB have closed, but new dispatchable low-carbon plants have not yet opened. By contrast, Renewable Energy Sources (RES, including solar PV, onshore wind and offshore wind) have been deployed because of the subsidy frameworks available to them, and are continuing to be deployed because of their cost-competitiveness in relation to other, more traditional methods of electricity generation.

Table 5-1: Historical capacities of renewable generation deployment and sites under scoping / application / construction (GW). Adapted from [13, 14, 95]

Technology (GW)	January 2011	March 2021	Projects under application / construction
Solar	0.0	13.3	4.9[3]
Embedded Wind	1.7	6.5	0.4[4]
Onshore Wind	3.8	6.0	11.1
Offshore Wind		10.8	55.8
Total	**5.5**	**36.6**	**72.2**

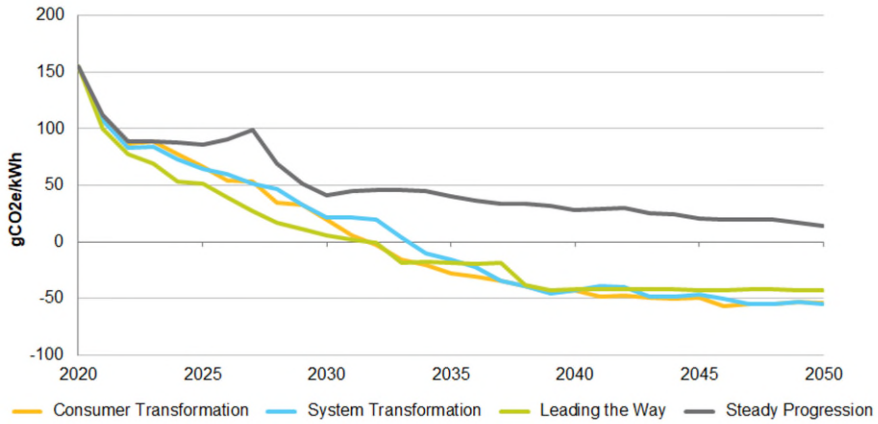
5.3 Action during the 2020s will be critical to meet the 2050 Net-Zero target

5.3.1.1 The timescales for building out new, large-scale generation projects are generally long. Those in planning today may not generate their first MWh of carbon-free electricity for a further 5 or more years. However the need for decarbonisation grows stronger each year, because every year during which no action is taken, more carbon is released into the atmosphere and the global warming effect accelerates. Therefore early action will have a correspondingly more beneficial impact on our ability to meet the 2050 targets than will later action. In June the IEA issued a call to arms on energy innovation, stating that "[The] world won't hit climate goals unless energy innovation is rapidly accelerated ... About three-quarters of the cumulative reductions in carbon emissions to get on [a path which will meet

[2] https://www.cfdallocationround.uk
[3] Includes projects which are listed on each Distribution Network Operator's Embedded Capacity Registers [95] but which are not yet commissioned, and NGESO's TEC Register [13].
[4] Includes projects which are listed on the Renewable Energy Planning Database [14], less those which are listed on NGESO's TEC Register [13]

climate goals] will need to come from technologies that have 'not yet reached full maturity'" [35, July 2020]. DNV GL expressed this observation in a different way: "measures today will have a disproportionately higher impact than those in five to ten years' time" [36].

Figure 5-2: Power generation emissions must reduce to negative in the early 2030s in order to meet 2050 Net-Zero targets [94, Figure SV.27]



5.3.1.2 Recalling from Chapter 7 that the UK's pathway to a successful 2050 carbon budget must involve wider transitions outside of the power generation sector, implies also that the power generation sector must first decarbonise in order to enable the successive decarbonisation of transport, industry, agriculture and the home. NGESO analysis points to the power generation sector being reduced to negative emissions in the early 2030s, as shown in Figure 5-2. The scale and pace of change required within this sector, in order to meet that target, is immense, and any delays incurred now, make the challenge increasingly more difficult for the years ahead.

5.4 Many technologies identified in LCTP are unlikely to reduce CO_2 emissions during the critical 2020s

5.4.1.1 Table 5-1 shows elements of the government's Low Carbon Transition Plan, made in 2009, which were expected to make significant contributions to reducing the carbon intensity of electricity generation. A recent status on these initiatives is also included. While a number of the major initiatives detailed in the 2009 Low Carbon Transition Plan have not yet delivered, carbon reduction targets for power generation are being met. This has provided a major contribution to the UK's current 'on-track' performance versus its legal decarbonisation obligations, and has been delivered predominantly by the closure of the existing coal fleet as well as an increase in renewable generation capacity.

5.4.1.2 As previously noted, FES 2020 and 2021 [6, 94] both describe three pathways involving radical change across many industry sectors, which will deliver the required 100% reductions in carbon emissions by 2050. The Net-Zero commitment underpins the urgency for new low carbon generation infrastructure to be built and commissioned, and government support for such developments is critical. The National Infrastructure Commission (NIC established in 2015 to provide independent, impartial advice on the UK's long-term infrastructure needs) stated in their first National Infrastructure Assessment report [37] that:

New nuclear power plants and carbon capture and storage infrastructure will not be built by the private sector without some form of government support. [37, p38]

5.4.1.3 FES 2012 [38] estimated that between 5 GW and 14 GW of Carbon Capture Usage & Storage (CCUS) could be operational (across coal, gas and biomass plant) by 2030. One of the biggest challenges with CCUS at the time of writing the LCTP, was that while each stage – capture, storage and transport – had already been shown to work, it had never been tried at a commercial scale on a power station and never the complete process from start to finish. As of today, Grid-scale CCUS from power generation has not yet been proven in Europe[5]. CCUS technology has not yet progressed to industrial scale, and no new large-scale carbon generating power stations with CCUS capability have yet been constructed in GB. Government do not foresee that CCUS will make any significant contributions to carbon reductions in GB until the 2030s [41 and 24, p115].

5.4.1.4 The UK chose to largely decarbonise its power sector by adopting low carbon sources quickly, but remained cognisant of the advantages to the UK of maintaining a diverse range of energy sources so avoid dependency on a particular fuel or technology type [3, Para 3.3.5], thus the continuation of support for CCUS through the 2010s. The NIC concluded in their 2018 assessment of national infrastructure [37], that CCUS would only become useful for decarbonisation of the electricity generation sector in the 2040s and beyond, when the decarbonisation and adequacy of electricity generation must already have been largely achieved in order to support decarbonisation in other sectors. A 2020 update to NIC's analysis [42] proposes CCUS be utilised with bioenergy to generate power at negative emissions, or produce hydrogen. Crucially the NIC presented CCUS as an alternative to nuclear generation rather than as a substitute for RES capacity.

5.4.1.5 The Prime Minister included within his Ten Point Plan, an ambition to develop 'world-leading technology to capture and store harmful emissions away from the atmosphere, with a target to remove 10 million tonnes of carbon dioxide by 2030' [31].

5.4.1.6 Recent progress in industrial CCUS developments include plans to capture up to 10m tonnes of CO_2 each year by the end of this decade [20, p17]. A separate project plans to take industrial European CO_2 and store it (also under the North Sea), locking in 8m tonnes each year (0.2% of Europe's 2017 emissions), again by the mid-2020s [43]. The common thread between these consortia is that they are led by traditional, integrated oil majors, representing significant capital availability, prior asset ownership and technical experience: therefore a strong credibility in their approach. However in aggregate, these flagship European projects represent less than 1% of Europe's 2017 CO_2 emissions. A significant pipeline of projects, commissioning in incredibly quick order, will be needed in order for CCUS to become a significant support to decarbonisation efforts in Europe before the mid-2030s and CCUS is prominent in the 2020 National Infrastructure Strategy and Energy White Paper. CCUS remains regarded as essential for Net-Zero, to decarbonise dispatchable power plants, decarbonise industry, produce low-emissions hydrogen and deliver greenhouse gas removal technologies. However such benefits will materialise if and only if projects become operational in time. Recognising that 'the technology has not been delivered at scale and

[5] Only two large-scale CCUS for power generation are currently operational (Boundary Dam (Canada) and Petra Nova (USA) [39] with only 20 projects in use across all sectors and worldwide [40].

significant risks remain' government has committed to:

- Invest £1 billion to bring forward four CCS clusters by the end of the decade, with two to begin construction by the mid 2020s;
- Set an ambition to capture 10 megatons of carbon dioxide per year by 2030; and
- Outline further details on new business models and revenue mechanisms to attract private sector investment. [1, p53]

5.4.1.7 Wave / Tidal power has been proposed at a number of locations in the UK, although wave technology development has experienced both cost and operational challenges [44]. Early predictions on future rollout of wave / tidal power were large but varied, ranging from 0.5 GW to 4.5 GW by 2030 [38, p54]. Tidal power remains complicated to consent, and expensive to deliver, a position made clear by governments' rejection of the Swansea Bay Tidal Lagoon in June 2018 [45].

5.4.1.8 Nuclear power has attracted significant government attention over the last decade, including plans for 16 GW of new build capacity by 2030, described in the 2013 Nuclear Industrial Strategy [46]. One new nuclear project (Hinkley Point C) is under construction and others either remain in their development phases, or have been abandoned. The potential contribution made by new nuclear will be discussed more fully in the following Section 5.5.

5.4.1.9 In summary, despite recent commitments from government to providing continued support for both technologies, neither nuclear power nor carbon capture and storage are likely to play a significant role in furthering decarbonisation before the 2030s due to the delivery risk and timing constraints associated with both.

5.4.1.10 Offshore wind power generation has global momentum and is already delivering GW-scale projects in GB. Offshore wind can already be classified as a large-scale renewable technology.

5.4.1.11 With this context, the attractiveness of offshore wind, a proven technology which will deliver significant benefits to consumers through decarbonisation, security of supply and affordability this decade, becomes clear. The IPCC has stressed the importance of urgent action to decarbonise electricity generation, and the CCC have reported that the UK need to commission more low-carbon generation, and more quickly, to meet its Net-Zero obligations. The prompt development and deployment of proven technologies, such as offshore wind, is a lower-risk pathway for delivering low-carbon generation both now and for the longer term.

5.4.1.12 The role that offshore wind has played in decarbonising GB's electricity generation to date is transparent within Table 5-2. Offshore wind has undergone significant technological advances in scale and efficiency, and the UK has 40% of Europe's wind resource [3, Para 3.4.3]. It is therefore for GB to make best use of this natural, renewable energy resource in order to meet its legal carbon emission reduction obligations.

5.4.1.13 Offshore wind generated nearly 40 TWh of power in 2019. this increased to 46 TWh in 2020 [94, Table SV.23]: a significant proportion of national demand. Offshore wind is well placed to play the significant role it has been allocated in recent government papers (40 GW by 2030, [1, p27]), and Chapters 8 – 10 of this report expand on the reasons behind this statement. Hornsea Four should therefore be considered to be a critical project at this stage of GB's journey to Net-Zero.

5.5 The potential contribution of new nuclear in the UK to reduce UK carbon emissions in the 2020s

5.5.1.1 It is important to clarify that this report does not seek to justify or promote the exclusion of any generation technologies other than Offshore wind from the future generation mix.

5.5.1.2 Nuclear represents the largest capacity of dispatchable low-carbon power generation and therefore is an incredibly important operational generation technology in the context of keeping current carbon emissions down. Nuclear has historically met approximately 20% of GB demand. For the time being, nuclear continues to generate approximately a 16% of demand, but existing nuclear is close to the end of its life. At the date of writing this report, Dungeness B (1 GW) has closed and firm closure dates have been set for a further 2 GW of nuclear capacity, during 2021 (Hunterston) and 2022 (Hinkley Point B). A further 2 GW (Heysham 1 and Hartlepool) will close during 2024. New nuclear projects are ongoing, one under construction and others in development, but whether new nuclear will be built out at the appropriate scale and pace so to continue to contribute a one-fifth share is not yet clear. It is therefore important to set out and assess the projected contribution of nuclear power to the reduction of UK carbon emissions within the context of current policy and project developments

Table 5-2: Projections from 2009 for a low carbon power sector, summarised from [16, 11, 68]; and a 2021 status [Author analysis]

Initiative	Projection	Status, September 2021
New Nuclear	2013: construction of new nuclear commences. 2018: first new nuclear operational (of up to 16 GW fleet)	2017: Hinkley Point C construction commenced, with a Commercial Operation date currently estimated during 2026 2018: Government advised by NIC to permit only one more GW+ nuclear before 2025 [37, pp10, 42] 2019/20: Two GW+ scale nuclear projects abandoned by their proposed developers. 2020: Energy White Paper is consistent with NIC advice [20, p16]. 2020/21: End of life announced for 4 GW of existing nuclear, in 2021 (1 GW), 2022 (1 GW) and 2024 (2 GW). One station (1 GW) enters decommissioning.
Wave / Tidal	2014: Larger-scale wave and tidal energy generation (>10 MW) starts to be deployed	2021: No larger-scale wave and tidal energy generation yet to be deployed. The second Severn Estuary / Swansea proposal was denied public funding in 2018.
CCUS	2020: up to 4 CCUS demonstration projects operational in the UK	2021: No CCUS projects yet operational in GB. Business model blueprints anticipated in 2021; two industrial clusters progress with project development. [1, p53]
Renewable Energy Share	2020: Around 30% of electricity is generated	2019: Wind, solar, hydro, bioenergy accounted for 37% of generation. Nuclear accounted for 17%.

Initiative	Projection	Status, September 2021
	from renewable sources	2021: NIC conclude that 65% of GB's electricity could be delivered from RES [37]; the CCC highlight the need for of 90 – 175 GW of offshore wind capacity in the UK by 2050 [2, Table 3.4.a]

5.5.1.3 The contribution new nuclear power may make to the GB power mix is, with the exception of Hinkley Point C (3.2 GW), likely not to commence earlier than the 2030s. With 5 GW of existing nuclear now already closed, or slated to close in 2024 or earlier, the low carbon electricity generated by nuclear power during the 2020s will reduce. Operational capacity will reduce from today's levels before new assets come on-line to replace them.

5.5.1.4 It is therefore vitally important that other deliverable, fundable, affordable and beneficial technologies are consented as a priority, in order to keep pushing carbon reductions lower. This directly strengthens the importance of current government policy on offshore wind to meeting our UK Net-Zero legal commitments.

5.5.1.5 The 2019 BEIS Consultation on new nuclear financing includes statements on forecast energy growth and the importance of renewable generation (alongside nuclear) in meeting that demand:

> *Meeting Net-Zero will require emissions from the power sector to be reduced to low levels and the deployment of negative emissions technology to offset emissions from those sectors that cannot be completely decarbonised. It is likely that electricity demand will grow significantly by 2050 as other sectors of the economy such as transport and heat are electrified, potentially nearly doubling (or more) from today's levels. To meet this increasing demand, whilst reducing emissions to low levels, there will need to be a substantial increase in low carbon generation – the Committee on Climate Change estimate a four-fold increase may be needed. This is at a time when seven out of eight of our existing nuclear power plants – important contributors to our low carbon generation – are due to come offline by 2030 as they reach the end of their operational lives. As the cost of renewable technologies such as offshore wind and solar continues to fall, it is becoming clear that they are likely to provide the majority of our low carbon generating capacity in 2050.* [47, p7]

5.5.1.6 This Statement of Need concludes that the Hornsea Four offshore wind project is needed in the UK, and developing the asset as planned, will meet government objectives of delivering sustainable development, ensuring our energy supply is secure and providing benefits to GB consumers. The delivery timing associated with current forward nuclear capacity projections strengthen this conclusion.

5.5.2 Nuclear projects have long development timeframes

5.5.2.1 A series of government white papers and consultations through 2007/8 was precursor to an enabling framework for a Great British nuclear renaissance. Over the subsequent 5 years, government removed successive barriers to nuclear development. This covered: site selection (the National Policy Statement for Nuclear Power Generation); regulatory approval of reactor designs (the Generic Design Assessment process); and revenue and back-end cost certainty (the Contract for Difference (CfD), a key element of the 2013 Electricity Market Reform, and the Funded Decommissioning and Waste Management Plan). The Energy Act 2013 also created a body corporate, the Office for Nuclear Regulation (ONR) to regulate, in GB, all nuclear licensed sites. These policy instruments clearly signalled that the UK was open to nuclear business and that it was now for commercial entities to bring new nuclear to market. The process which needs to be followed however is neither easy, nor short.

5.5.2.2 From a regulatory perspective, the Generic Design Assessment (GDA) of a reactor is a voluntary process undertaken by the ONR taking 4–5 years to complete, and may be applied for ahead of an application for a Nuclear Site Licence (NSL). GDA gives a clear indication of whether the design would meet safety, security and environmental regulatory requirements, and simplifies the necessary NSL and Planning Consent applications. The site-specific NSL is granted by ONR, who may take up to 18 months to assess the capability and resources of the applicant organisation, the site safety case and other site-specific factors. Planning consent should be quicker having secured GDA approval, assuming appropriate and successful community consultation has taken place.

5.5.2.3 Aside from achieving these consents, the applicant must confirm its commercial arrangements. There are potentially three main agreements: Shareholder investment agreements (if the applicant is a JV); the CfD or equivalent commercial arrangement which provides increased revenue certainty for the applicant; and the Secretary of State Investor Agreement (providing protection for the applicant and (ultimately) consumers, against significant changes to project economics or market arrangements). Once secured, the real task of digging dirt and pouring concrete can begin. During construction and commissioning, the NSL introduces at least 5 separate hold points. These may only be moved past when consent has been granted by the ONR.

5.5.2.4 The development timeline for the Hinkley Point C project (currently under construction and currently anticipated to operate from 2026) has been illustrated in Figure 5-3.

Figure 5-3: HPC Timeline [Author analysis]

HPC Timeline	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021 +
Approvals	1. NSL granted 2. GDA achieved	3. Planning consent granted		4. Strategic investment agreement	5. Contract for difference 6. SoS Investor agreement					
Site Works	<------------------		Groundwork preparations		----------------->	<---	Civils construction	--->	Nuclear construction	----->

5.5.3 Progress in the development of nuclear projects

5.5.3.1 Hinkley Point C (HPC) is currently under construction in the UK by an EDF Energy / China General Nuclear (CGN) partnership: Nuclear New Build Generation Company (NNB). The technology employed will be a UK EPR, designed by EDF and Areva. The GDA process commenced in 2007, and nuclear (as opposed to civil) construction commenced in late 2018 – a project development timeframe lasting 11 years.

5.5.3.2 HPC construction has been impacted by the COVID-19 pandemic, but construction milestones for the second reactor have been achieved in line with the anticipated schedule (securing schedule gains to progress of 30% to date versus the first reactor [48]), so

Commercial Operation Date (COD) remains forecast during 2026 [49, 50].

5.5.3.3 In 2016, the Low Carbon Contracts Company signed a CfD with NNB for the Hinkley Point C project, guaranteeing power price for a 35-year term. Since signing this agreement, there has been a shrinking appetite for another HPC-style CfD contract in the UK energy market, and a growing view that a different approach is needed.

5.5.3.4 Government's Energy White Paper, published in December 2020, sets the scene for further nuclear development in GB and confirms through their summary of responses received to the 2019 Regulated Asset Base for nuclear (RAB) consultation, indicate 'that a RAB model remains credible for funding large-scale nuclear projects' [18, p49].

5.5.3.5 Sizewell C (SZC), also EDF/CGN, is progressing through its development phase. A project aiming to build the third and fourth UK EPR, SZC may proceed through planning, consenting and construction more rapidly than HPC, once funding mechanisms have been agreed. EDF have formally stated[6] that: 'the [SZC] project does not currently have a timeline ... although construction work could overlap with Hinkley Point C', SZC 'will take 9-12 years to build' and has unofficially been forecast to come online in the early 2030s [49]. In December 2020 government confirmed that it is to enter negotiations with EDF in relation to the Sizewell C project as it considers options to enable investment in at least one nuclear power station by the end of the current Parliament (i.e. no later than May 2024).

5.5.3.6 CGN have taken the lead on the Bradwell B project. GDA on their reactor design started in 2017, with conclusion anticipated in 2022. No indications of intended project timelines have been published by the developer, however an assessment of potential earliest commercial operation date for this reactor, based on development durations of other projects, may be in the mid/late 2030s.

5.5.3.7 Government remains committed to ensuring all technologies have a part to play in the future energy mix, providing that they offer value for money for consumers. Nuclear power can achieve this through either the delivery of larger projects (see Section 5.5.5) or Small Modular Reactors (SMRs). SMRs aim for cost improvements through the production of multiples of units rather than an increase in scale. In 2015, the Energy Technologies Institute (ETI) published a report into the enabling framework required to realise such a vision. This included a 'manufacturing line' capability to deliver efficiency and accuracy in the modular construction techniques [51] and in October 2017, as part of the Clean Growth Strategy, government announced that it will invest up to £7 million (£5 million to ONR and £2 million to the Environment Agency) to further develop the capability and capacity of the nuclear regulators to support and regulate the development of Advanced Nuclear Technologies, including SMRs.

5.5.3.8 ETI's analysis showed (for a more conventional water-based reactor design) a minimum 17-year development timeframe from the initial design concept through to commissioning of the first production unit. ETI do note that some SMR concepts may already have progressed along this timeframe.

5.5.3.9 The earliest delivery of a first of a kind SMR is therefore not likely to be before the mid-2030s, although ETI consider that this timeframe may extend by up to 9 years for more evolutionary

[6] https://www.edfenergy.com/energy/nuclear-new-build-projects/sizewell-c/about

designs. A global leading design, the American NuScale SMR, plans its first US installation by 2030 [52], three years later than previously planned. Other designs are at pace or behind NuScale.

5.5.3.10 In July 2020, government announced a £40 million kick start to develop the next generation of nuclear energy technology, supporting three "Advanced Modular Reactor" projects – i.e. those less conventional technologies with longer design timeframes than anticipated in the ETI report. Meanwhile, a consortium approach to the development of a conventional SMR is being undertaken. No design has yet been submitted for Generic Design Assessment in the UK, but the GDA process has been readied for the potential of SMR applications, and will open in 2021 [18, p50]. The 2020 National Infrastructure Strategy confirms government's continued support for the development of nuclear technologies:

> *The government will provide up to £525 million to bring forward large-scale nuclear and invest in the development of advanced nuclear research and development (R&D), including up to £385 million in an Advanced Nuclear Fund for small modular reactors and advanced modular reactors. This is alongside £220 million for nuclear fusion.* [1, p52]

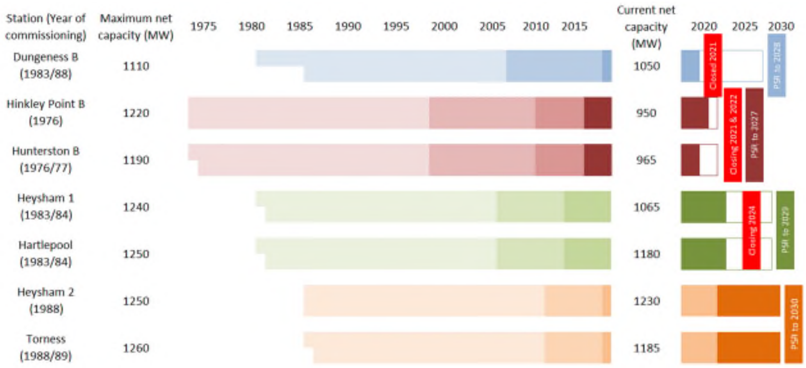
5.5.3.11 The most recent possible indicator for the potential role of nuclear within a future energy landscape appears in the CCC Balanced Net-Zero Pathway for electricity generation, which states that: 'Despite retirements of existing nuclear plants in the 2020s, this scenario sees new nuclear projects restore generation to 2020 levels by 2035. The Balanced Pathway reaches 10 GW of total nuclear capacity by 2035, with 8 GW of new-build capacity' [2, p135], implying that Hinkley Point C, and a combination of at least one other large-scale project and / or small modular reactors must be operational before 2035 to meet the levels of decarbonisation recommended for the sixth carbon budget.

5.5.3.12 The National Infrastructure Strategy does not go as far as to indicate a target for the future role of nuclear technology, stating only that 'government is pursuing large-scale nuclear projects, subject to clear value for money for both consumers and taxpayers and all relevant approvals'. The Energy White Paper sets out government's commitment to aim 'To bring at least one large-scale nuclear project to the point of Final Investment Decision by the end of this Parliament, subject to clear value for money and all relevant approvals.' [18, p16]

5.5.4 Decommissioning GB's existing nuclear power stations

5.5.4.1 By their initial lifetime expectations, almost all of the UK's existing reactors should by now have closed, however successive lifetime extensions have kept them running for longer than expected. Current operator expectations for plant closure dates for the Advanced Gas Cooled Reactor (AGR) fleet are displayed in Figure 5-4: Generating capacities and announced closure dates for each AGR station [Author analysis of data sourced from www.edfenergy.com].

5.5.4.2 In June 2021 EDF energy announced that Dungeness B (1 GW), would move immediately to defueling and decommissioning: the first of the AGR fleet to close. Further life extensions are looking less possible at the AGR, as graphite cracking in the core of the two oldest stations (Hunterston B and Hinkley Point B) has also pushed operator EDF Energy to announce the closure of Hunterston B in December 2021 / January 2022 and of Hinkley Point B in June/July 2022. Hartlepool and Heysham 1 will follow by 2024.



5.5.4.3 Therefore just two stations will remain operational in the AGR fleet post 2024 (Torness, Heysham 2): a total generation capacity of c. 2.4 GW, until 2030 at the latest.

5.5.4.4 The UK's only Pressurised Water Reactor, the 1.2 GW Sizewell B is currently scheduled to close after 40 years operation, in 2035, but 20-year life extensions to PWRs are globally commonplace.

5.5.5 A synthesis of new nuclear commissioning date projections

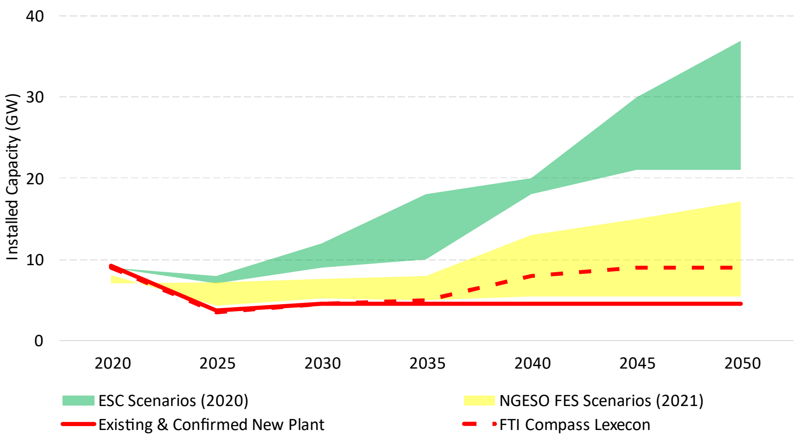
5.5.5.1 The conclusion of the narrative in the previous section is illustrated in Figure 5-5, which shows that capacity from current and committed new nuclear projects (at the time of writing: only HPC) will reduce between now and 2030. Without a significant and immediate drive from government to commit to further nuclear projects, nuclear capacity will most likely remain lower than current levels until 2035. Therefore, although nuclear will play an important role in the generation of low carbon electricity through the 2020s, the contribution it will make to achieving Net-Zero will be lower in each year from 2023 until at least the mid 2030s than is currently the case. This gap must be made up.

5.5.5.2 The commitment by government to specific nuclear projects which start to deliver some of the growth scenarios illustrated in Figure 5-5 will, if secured, provide additional confidence to the role that nuclear generation will be asked to play in the journey to Net Zero. The Prime Minister's November 2020 plan for green recovery includes the ambition to 'Push nuclear power as a clean energy source and include[s] provision for a large nuclear plant, as well as for advanced small nuclear reactors' [33]. The CCC sixth carbon budget includes nuclear capacity scenarios between 5 GW and 10 GW by 2035, and maintained within those bounds through to 2050 [2, p135 and Table 3.4.a]. Other low carbon generation projects, which have shorter timeframes than nuclear projects for consenting, financing and construction, will be needed to fulfil, and will be capable of fulfilling, a critical role in supporting decarbonisation in the 2020s and early 2030s independent of decisions any nuclear plans.

Figure 5-4: Generating capacities and announced closure dates for each AGR station [Author analysis of data sourced from www.edfenergy.com]

5.5.5.3 This analysis is relevant to the Hornsea Four project, because it demonstrates the importance of urgently bringing forward significant capacities of deliverable low carbon power, so that it might support the decarbonisation of the UK electricity sector in the critical 2020s/2030.

Figure 5-5: Projections of current nuclear capacity as existing stations close. Source: [94, 7, 8, Author Analysis, www.edfenergy.com]



6 Recovery from COVID-19

6.1 Setting the scene on COVID-19

> *As nations move out of the shadow of coronavirus and confront the challenge of climate change with renewed vigour, markets for new green products and services will spring up round the world.* [18, p4]

6.1.1.1 Government has consistently shown its commitment through the 2020 COVID-19 pandemic, to build back greener in order to tackle climate change and stimulate economic recovery. During the Summer 2020 COVID-19 lockdown period, power demand and power price were significantly down year-on-year. The threat of significant long-term effects remains present, lockdown impacts potentially feeding through into a weak economy resulting in a high risk of industrial and commercial business closures. However, although the fight against climate change requires urgent action, it also requires sustained action over a long timeframe, and government have begun a strategy of 'build back stronger' through 'fairer, faster, greener' investment [1]. The near-term impacts of the COVID-19 pandemic are therefore not anticipated to negatively impact the continued development of long-term energy infrastructure assets, rather the national need to make long-sighted investments now which support a green recovery from 2020's difficult times is anticipated to support energy infrastructure investments. The Energy White Paper puts in place a strategy for the wider energy system that:

- Transforms energy, building a cleaner, greener future for our country, our people and our planet; and
- Supports a green recovery, growing our economy, supporting thousands of green jobs across the country in new green industries and leveraging new green export opportunities [18, p4].

6.2 GB electricity demand during Summer 2020

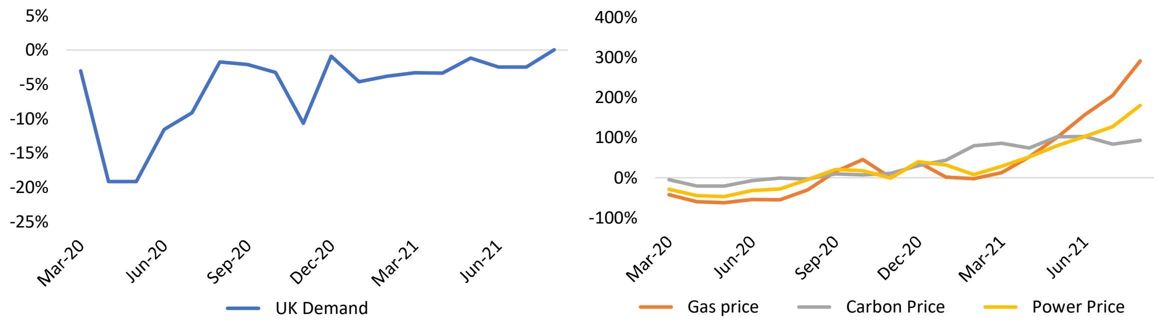
6.2.1.1 Electricity demand in the UK dropped during lockdown as industry shut down to contain the virus. Headline reports were of major reductions in demand with more severe impacts on year-on-year movements in gas and electricity prices.

6.2.1.2 Figure 6-1shows the raw trends in electricity demand and the major fuel markets by comparing the percentage change in average value by month in 2020 and 2021 with the monthly average value for the same month in 2019. The data shows that at the height of the first UK lockdown, average demand dropped 20% year-on-year; that gas dropped in price by over 60%, power price by nearly 50% and carbon (EUA) price by 20%. As lockdown restrictions gradually lifted through August and September, market levels rose again, and prices since September 2020 have been higher than they were in 2019.

6.2.1.3 Fuels and power prices have responded to global shifts in supply and demand, UK power responding to global gas and coal prices, and the price placed on carbon through the European Emissions Trading Scheme, and since May 2021 the UK Emissions Trading Scheme. At the time of writing this report, all three charted commodities are trading at all-time high levels.

6.2.1.4 Through a weekly Operational Forum, NGESO estimated that demand has been tracking within 2% of 2019 actuals since November 2020, a trend continued into December despite a second lockdown. Just months after the first lockdown, and arguably during the second, industry found new ways to adapt to lockdown measures, and life has adapted to a 'new norm' which is anticipated may be quite different to the 'old norm' in many ways. Only our collective actions over the coming months and years will determine exactly how; and forward forecasts are varied with wide differences between 'high' and 'low' scenarios.

Figure 6-1: Change in absolute levels of demand (left hand side) and gas, carbon and power market monthly averages (right hand side) compared to the same month in 2019 [Author analysis, from market data]



6.2.1.5 An illustration of the short-term effect of the pandemic on projected UK demand is shown in Figure 6-2, which illustrates data published by consultancy EY. Their published analysis (dated March 2021) forecasts a drop in electricity demand during 2021 and 2022 (relative to a pre-pandemic baseline forecast). Beyond 2023 however, EY now expect that electricity demand will increase more rapidly than their pre-pandemic projections, as a result of deeper and more accelerated electrification, particularly across heat and transport, in response to the climate crisis and government's policy response.

6.2.1.6 There are two critical points arising from this analysis. Firstly, although as a result of the pandemic, UK electricity demand is currently down in comparison to recent history, the need for and delivery of a green recovery is expected to return electricity demand to sustainable growth levels within the next years and the pandemic has not damaged the long term prospects for electricity demand to increase significantly in the timeframe to 2050. Secondly, in an increasingly global and volatile commodity fuels market, an increase in the capacity of offshore wind generation will help the UK to increase its indigenous generation and therefore help keep a grip on power prices. Chapter 10 has further details.

6.3 Environmental health and public health are linked

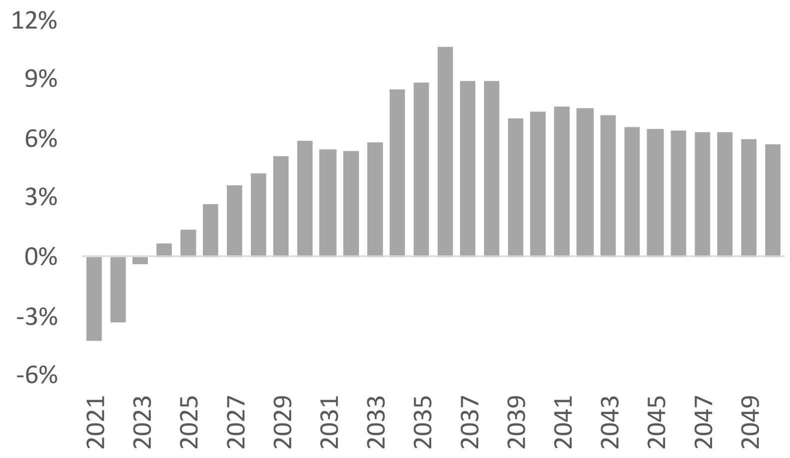
6.3.1.1 Correlations between air pollution levels and risk of death from COVID-19 have been found by some researchers. High levels of fine particulate pollution in the US (generated largely from fuel combustion from cars, refineries, and power plants) has been linked with risk of death from COVID-19 e.g. [53]. This link having been established, the inter-generational aspect of global warming, used by some to delay making decarbonisation decisions now because of the potential costs of action, which today's economies would have to bear but from which future economies would benefit, would lose its edge. By reducing fine particulate pollution now, almost immediate positive health effects can be brought to today's citizens:

a direct cost / benefit relationship which supports the need to decarbonise with urgency.

6.3.1.2 A study by the Office for National Statistics (ONS) was reported, in August 2020, to have found that 'single-unit increase in pollution exposure over long term may increase [COVID-19] death rate by up to 6%' [54]. Along with these findings from the UK and US, Chinese and Dutch studies have also made similar conclusions. Replacing polluting industry with clean air industry, will help reduce death and illness now, and in the future.

6.3.1.3 COVID-19 drove carbon emissions down through a reduction in economic activity and therefore energy requirement. Correspondingly, many environmental indicators were (and remain) up. Skies were clear, pollution haze disappeared, fine particulate pollution reduced. Nature rebounded in many places, and many health indicators also ticked upwards. COVID-19 is an opportunity not to rest on climate ambition, but to reset climate ambition levels higher still. COVID-19, for its many negative and destructive effects, has given an adrenaline shot in the arm to environmental movements.

Figure 6-2: EY projections of the potential impact of COVID-19 on future UK Electricity Demand 2021 – 2050 (Change in forecasts dated Mar-21 versus Jan-20) [Author adaption of EY Consulting forecast]



6.3.1.4 The experience of lower carbon emissions and better air quality has provided a stimulus for what could be achieved in respect of the public health benefit of a lower-carbon society and the Prime Minister's Plan for a Green Recovery seizes the opportunities of today to drive economic recovery and environmental and public health improvements through the development of green infrastructure, such as 40 GW of offshore wind.

6.3.2 Economic and social recovery from COVID-19

6.3.2.1 In June 2020, the Business, Energy and Industrial Strategy (BEIS) Committee launched an inquiry on Post-Pandemic Economic Growth. The inquiry was established to consider all options available to government to secure the UK's economic recovery from the impact of COVID-19, covering: investment; industrial strategy; jobs; skills; exports and sustainable growth. The inquiry is likely to examine the measures needed to stimulate economically and environmentally sustainable growth, and investigate whether the post-pandemic world presents an opportunity for a resetting of the UK economy and (among other themes) to drive forward progress on broader government priorities including the delivery of green growth and speeding up progress on delivering Net Zero.

6.3.2.2 In June 2020, the Prime Minister challenged the UK to 'build better and build greener but also build faster', saying that 'the UK would lead in markets and technologies such as net zero planes and long-term solutions to global warming such as solar, wind, nuclear, hydrogen and carbon capture and storage.' [27]. By July 2020, government had already committed £350m to 'supercharging green recovery' [28].

6.3.2.3 The CCC provide strong direction in their 2020 Progress Report to Parliament [24]. They present evidence of how a range of low-carbon and climate adaptation 'green stimulus' measures can fulfil both the short-term needs (protecting workers and businesses and rebuilding a greener economy) and long-term needs (investing in key assets to build capacity and enable productive activity in the future) arising from the COVID-19 pandemic [24, p15], and paint the picture of an opportunity to pivot the economy to long-term environmental solutions. A green lung, rather than an iron lung, for the UK.

6.3.2.4 In November 2020, in anticipation of the publication of government's Energy White Paper, Energy Minister Kwasi Kwarteng confirmed that government remained committed to domestic and international efforts to tackle climate change; and explained that government would 'Build on [the new energy white paper] to deliver a stronger greener and more sustainable[e] economy after the pandemic … relying on experts … to drive forward the agenda along our path to net zero' [55]. The Prime Minister's Ten Point Plan, part of a broader £12 B package of public investment, provides further evidence that government remains focussed on delivering in this important sector [31].

> *Fighting climate change offers huge opportunity for both growth and job creation … the time is now to seize these opportunities.* [18, p2]

7 Future demand for electricity is uncertain but growing

7.1 Setting the scene on GB electricity demand

> *[Government] expect[s] that demand for electricity is likely to increase, as significant sectors of energy demand (such as industry, heating and transport) switch from being powered by fossil fuels to using electricity. As a result of this electrification of demand, total electricity consumption … could double by 2050.* [3, Para 3.3.14]
>
> *Whilst no such projections of the UK's future energy mix can be definitive, they illustrate the scale of the challenge the UK is facing.* [3, Para 3.3.21]

7.1.1.1 The annual demand for energy from all sources in GB in 2020 was 1,369 TWh, with 19% (258 TWh) in the form of electricity [94, Chart CV.1]. While our total energy demand must reduce significantly by 2050, electricity demand is expected grow as carbon-intensive sources of energy are displaced by electrification of other industry sectors, or production of non-carbon energy vectors by use of electricity. The NGESO Future Energy Scenario (FES) reports provide critical information on these points.

7.2 Expert analysis of the future energy sector

7.2.1.1 The future characteristics of GB's energy and electricity demands are described through a set of possible scenarios developed (through industry consultation) on an annual basis by GB's Electricity System Operator and statutory undertaker, NGESO. This annual publication is called Future Energy Scenarios (FES)[7], see [94] for the most recent publication. In completing their work NGESO look at a number of inputs including legislation, policy, technology and commercial drivers. Consumer behaviour is also considered. On their website, NGESO state:

> *All our scenarios consider energy demand and supply on a whole system basis, incorporating gas and electricity across the transmission and distribution networks. We continually develop all aspects of our Future Energy Scenarios process ensuring that the outputs are as rich and robust as possible to provide a sound reference point for a range of modelling activities. This includes extensive stakeholder consultation and detailed network analysis, which enables NGESO to identify strategic gas and electricity network investment requirements for the future.*

7.2.1.2 FES publications go back to at least 2012 (see http://fes.nationalgrid.com/fes-document/fes-archives/). The speed of decarbonisation is a key feature in each edition of the FES since 2018, with three of the four scenarios from FES 2020 meeting the 2050 carbon reduction target via distinct pathways, requiring heavy investment in either energy efficiency, or electricity decarbonation, and/or new or enhanced energy vectors[8] (e.g. hydrogen). In reality, these pathways are not mutually exclusive, and government and industry are currently pursuing initiatives which cover all possible stepping-stones to Net Zero.

[7] http://fes.nationalgrid.com.

[8] Energy vectors enable energy to be transported or transmitted and then converted back into another form of energy for end (or onward) use.

7.2.1.3 The future scenarios in Figure 7-1 describe one of the three NGESO 2021 scenarios which meet the 2050 emissions objective (System Transformation), and the one which does not (Steady Progression).

7.2.1.4 One important development in FES documents since 2019, and a direct result of the increasing urgency of the requirement to meet Net-Zero, is the growing prominence of a hydrogen economy in those FES scenarios which achieve the 2050 requirement, although hydrogen has for a long time been acknowledged as having potential to facilitate deep and broad decarbonisation by providing “difficult to reach” sectors with access to zero-carbon fuels. The relevance of the hydrogen economy, and the potential for hydrogen to play an increasingly important role in the energy ecosystem of the future, is two-fold for the development of Hornsea Four:

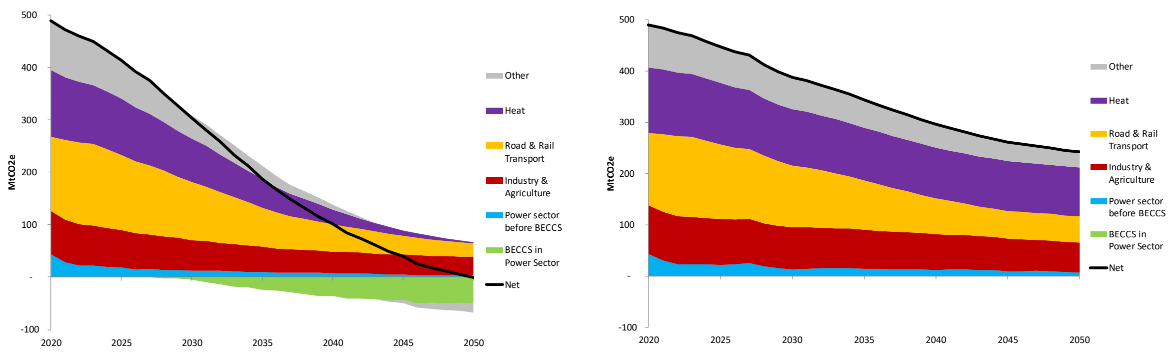
- The increased use of hydrogen as a low-carbon energy vector will increase the demand for electricity; and
- Potential incorporation of hydrogen as a storage vector as part of the installed Hornsea Four facilities.

7.2.1.5 For more information see Section 11.4

7.2.1.6 The most recent FES [94] brings together future operation of existing generators, and future trends in the demand for energy, to conclude that:

- Net emissions from the power sector likely must be net negative from the early 2030s to achieve Net-Zero;
- Hydrogen and carbon capture and storage are likely to be required to achieve Net-Zero, with in excess of 29 TWh of electricity demand required by 2040, and in excess of 95 TWh by 2050, for hydrogen production (including electrolysis connected to non-networked offshore wind). This is likely to increase the need for low-carbon electricity generation over and above that needed to meet other growth in electrification [94, Table SV.14]; and
- Offshore wind is, based on current economics, likely to be the most significant (and one of the cheapest) source(s) of electricity in the 2050 energy mix. A diverse mix of low-carbon generation is required to meet national decarbonisation targets.

Figure 7-1: NGESO scenarios, showing the importance of a whole-society approach to decarbonisation and low carbon electricity generation [Adapted from 94, Figures NZ.5]



System Transformation   Steady Progression

7.2.1.7 In March 2020 the Energy System Catapult (ESC) published a report, 'Innovating to Net-Zero' which summarised the results of an update to their national Energy System Modelling Environment, ESME [7]. The aim of the analysis was to consider potential pathways to 2050 in order to support the identification of technologies, products and services which will be most important to achieving the Net-Zero target. The ESC's analysis provides a useful independent analysis of the trends described in the FES and therefore provides useful confirmation of some points, while drawing different conclusions on others. The ESC's analysis adds breadth and depth to the consensus of how best to achieve the Net-Zero target. Other professional organisations also share their views of future demand and these are discussed in Section 7.4.

7.3 Future electricity demand

7.3.1.1 In the 1990s and early 2000s GB electricity demand grew only slowly, but since 2005 has fallen. The underlying demand reduction trend reflects three drivers:

- A decline in economic growth rate (particularly with the recession of 2009);
- A reduction in the level of electricity intensity as the UK economy has shifted to less energy-intensive activities; and
- The introduction of energy efficiency measures, especially more efficient lighting within the last seven years.

7.3.1.2 Today's view of future demand remains uncertain, particularly as a result of the COVID-19 pandemic as discussed in chapter 4, but growing, for the same reasons as those stated in the 2011 NPS documents:

- The switching of sources of final use power for heating and transport from carbon-intensive sources to electricity, the generation of which can be decarbonised using technologies already available today, will put upward pressure on demand.
- The least-cost energy efficiency measures, such as introduction of low-voltage LEDs for lighting, have now been implemented across business and domestic sectors; and
- Economic restructuring in the UK away from manufacturing to a service-based economy has largely occurred, however the growth of new high-technology and highly skilled manufacturing, both contributing to national economic growth and prosperity, is likely to place additional pressures on the electricity sector.

7.3.1.3 These observations are consistent with those made by NGESO in their FES 2020. Of the four scenarios in the 2020 only one (Steady Progression) does not meet Net-Zero.

7.3.1.4 There are many expert projections of electricity demand in 2050, and the majority of forecasts are for electricity demand to increase (from today's level of circa 300 TWh). The amount by which they increase varies according to the level of decarbonisation of non-energy sector demand, and the source for that decarbonisation. For example (see Section 11.4) hydrogen is an important energy vector which may be able to help decarbonise hard to reach sectors of transport, space heating and heavy industry. Off-grid hydrogen production would require the generation of low-carbon power but this would be counted outside of the transmission system demand projections for 2050 (i.e. in addition to the values presented in the following list):

- The National Policy Statements foresaw a doubling of current demand [3, Para 2.2.22], i.e. to circa 600 TWh;

- NGESO present a range from 388 – 494 TWh, excluding electricity demand for the purposes of producing hydgogen [94, Chart CV.1];
- The National Infrastructure Commission forecasts 465 – 595 TWh [42, p35];
- The Energy Systems Catapult forecasts 525 – 700 TWh [7, pp23&27];
- The Q4 2020 EY Power Price Outlook for GB forecasts 485 TWh [EY Consulting forecast];
- The CCC's sixth carbon budget presents a range from 550 – 680 TWh [2, Table 3.4.a];
- The BEIS impact assessment for CB6 presents a range from 610 - 800 TWh [96, p29];
- The 2020 Energy White Paper presents a range from 575 – 665 TWh [18, p42].

7.3.1.5 The ESC underpin their scenarios with the premise that "Net Zero requires switching to low carbon technologies wherever we can" including hard-to-treat activities as well as carbon sequestration. Critically the ESC conclude that Net-Zero requires society-wide adoption of low-carbon heating and transport technologies as well as continuing to drive "upstream" changes in the electricity mix and reduced energy use in industry [7, p5].

7.3.1.6 In the ESC scenarios, population growth and societal habits drive underlying demand growth, with either centralised or society-led decarbonisation supporting their demand forecasts. Industrial demand overall is forecast to decrease by between 20% and 30% due to a move away from energy-intensive industry and an adoption of energy efficiency measures wherever possible.

7.3.1.7 Further similarities between the ESC report and the FES are that a hydrogen economy must be created to decarbonise hitherto "hard to reach" end uses; the production of hydrogen through electrolysis may act to increase further electricity demand; and the transport sector, which also requires fundamental transformation, will need to be a strong adopter of hydrogen (for heavier freight) is emissions are to fall. Other forecasts are closely aligned with these views.

7.3.1.8 However it remains prudent to plan on a conservative basis to ensure that there is sufficient supply of electricity to meet demand across a wide range of future scenarios, including where the use of hydrogen is limited.

7.4 Transport

7.4.1.1 Surface transport was the largest source of UK greenhouse gas emissions (surface transport accounted for 24% of 2019 emissions, [24, p21]) however surface transport emissions fell by 19% [97, p64] year-on-year due predominantly to the COVID pandemic. Emissions are expected to rebound in 2021 as lockdown restrictions are lifted. A rapid shift to low emission vehicles will give a significant boost to the enduring decarbonisation of our economy.

> *The emissions from passenger cars and light goods vehicles make up over two thirds of all transport emissions, so decarbonising those forms of transport is a priority.* [18, p92]

7.4.1.2 Growth in the use of electric vehicles (EVs) is expected to create significant new demands on our supply of electricity. The UK government has proposed a ban on the sale of all new petrol and diesel vehicles to be effective from 2030 [31], bringing further forwards a prior indication of 2035. The Prime Minister's November 2020 announcement, confirmed alongside a ban on sales of new hybrid vehicles by 2035 within the Energy White Paper [18, p92] brings emerging government policy in line with the CCC's latest recommendation: that the date for phasing out petrol and diesel cars and vans (including hybrids) should be brought forwards to no later than 2032, with EVs supported by detailed policy arrangements to be able to fill the light transport gap this would create [24, p19]. Innovation is bringing affordable and highly desirable low emission private road vehicles to market, with almost every major brand now sporting a fully electric model and EV costs reducing. In September 2020, market frontrunners TESLA unveiled a new EV battery design which 'will enable the company to produce a $25,000 electric car in the next three years' [57].

7.4.1.3 The UK has put leadership of transport revolution at the heart of its Industrial and Clean Growth strategies, with investment being directed into both electric vehicle manufacturing, battery manufacturing and grid recharging points. In late June 2020, the Prime Minister committed to backing the vision of the UK becoming a global leader in developing batteries for electric vehicles [27]. Specifically, commitments were made to:

- Make funding available in 2020 to attract investment in 'gigafactories', which mass produce batteries and other electric vehicle components, enabling the UK to lead on the next generation of automotive technologies;
- Make £10m of funding immediately available for the first wave of innovative R&D projects to scale up manufacturing of the latest technology in batteries, motors, electronics and fuel cells, and nearly £500m for battery manufacture in the UK; and
- Provide additional funding to allow the progression of initial site planning and preparation for manufacturing plants and industry clusters, with sites under consideration across the UK – forming part of the government commitment to spend up to £1 bn to attract investment in electric vehicle supply chains and R&D to the UK. [58, 59]

7.4.1.4 These commitments came on top of the over £1 bn provided at the Spring Budget 2020 to support the rollout of ultra-low emission vehicles in the UK via support for a super-fast charging network for electric vehicles, and extension of the Plug-In Grant schemes. In late July 2020, the Mayor of London joined with local utilities to announce funding of £1.5bn for infrastructure work, including upgrading utility supply networks and boosting the EV charging infrastructure across the capital [60].

7.4.1.5 The government position is that EVs will be a critical new technology, vital in the fight against climate change. The commitments made above are evidence that there is strong political support for the rapid development and rollout of EVs, and with them will come additional electricity demand. EVs are predicted to play a major part in the future GB electricity mix as a result of their energy demand requirements (moving from fossil fuels to clean electricity) and potentially also their electricity storage capabilities. Ofgem have announced a plan to 'Enable drivers to go electric by supporting an energy network that can power 10 million electric vehicles by 2030' [61, p7] and anticipate that the number of electric vehicles on UK roads may grow from 320,000 at June 2020 [18, p93], to 46 million by 2050 [61, p4]. The FES suggests a more conservative number, due to trends to share cars and increase mileage per car in order to achieve Net-Zero, with scenarios ranging from 20 million to 33 million cars on UK roads in 2050, all adding approximately 100 TWh to electricity demand annually [94, Tables CV.31-35].

7.4.1.6 Hydrogen is well placed to help decarbonise hard to reach subsectors of transport (particularly larger, long-haul, road freight vehicles) and is making tangible steps towards mainstream use in this and other transport subsectors. In September 2020, the first UK train journey was powered by hydrogen. In the same month, the maiden flight by a hydrogen-powered commercial aeroplane was made [62, 63]. Annual electricity demand from road transport as a whole (i.e. incorporating both EVs and vehicles powered by hydrogen) could be 130 – 150 TWh in scenarios which meet Net Zero [94, Tables CV.31-33]. This projection is consistent with previous projections from 2019 and 2020 [6, Tables CV. 23-26], [56, p77] and [64, p12]. The use of hydrogen in rail and air travel will increase these estimates even further.

7.4.1.7 To support efforts in the decarbonisation of heavy-duty transport, government has pledged to invest £20 million in 2021 in freight trials to pioneer hydrogen and other zero emission truck technologies; and £120 million in 2021/22 to start the delivery of the 4,000 zero emission buses [18, p94].

7.4.1.8 Similarly, the ESC scenarios also foresee the decarbonisation of transport as a major influence to future electricity needs, anticipating approximately 35 – 40 million battery EVs on the roads by 2050 and only small numbers of PHEV or hybrid vehicles remaining operational. Hydrogen is anticipated by the ESC to be the major fuel for heavy transport. [7, pp22&25]

7.5 Home heating

7.5.1.1 In order to reduce the UK's dependence on natural gas thereby reduce further our carbon footprint, the long-term need to diversify to low-or zero-carbon home and industrial / commercial heating, cooking and hot water either directly through electrification, indirectly using electricity to produce hydrogen or by other renewable technologies, will, coupled with meeting the government's plans for new homes, also increase demands on the NETS. For every household that is supplied with electricity, an average additional burden of at least 4 MWh per year could be placed on the grid [65, p9]. Projections are that UK should be building at least 200,000 new homes a year [65, p7], implying a potential additional increase in electricity demand by at least 24 TWh per year by 2050. The Prime Minister announced in November 2020 his intention to bring forwards, to 2023, the date by which new homes will need to be warmed without using gas heating [31]. Even if GB is currently able to meet its current electricity needs and share of renewable generation targets now, it will be very difficult – if not impossible – to do so into the medium and long term, without the deployment of significant capacities of new low- or zero-carbon generation.

7.5.1.2 The ESC anticipates a hybrid approach to home and space heating, with electric heat pumps being installed in thermally efficient homes, and hydrogen or electricity providing heating for peak periods and/or cold spells. These measures are also included in the Energy White Paper: government aims to grow the installation of electric heat pumps from 30,000 per year to 600,000 per year by 2028; and will consult on whether it is appropriate to end gas grid connections to new homes, in order to open the market of homes not on the gas grid to heat pumps or other clean energy alternatives, representing some 50,000 to 70,000 installations a year [18, p110].

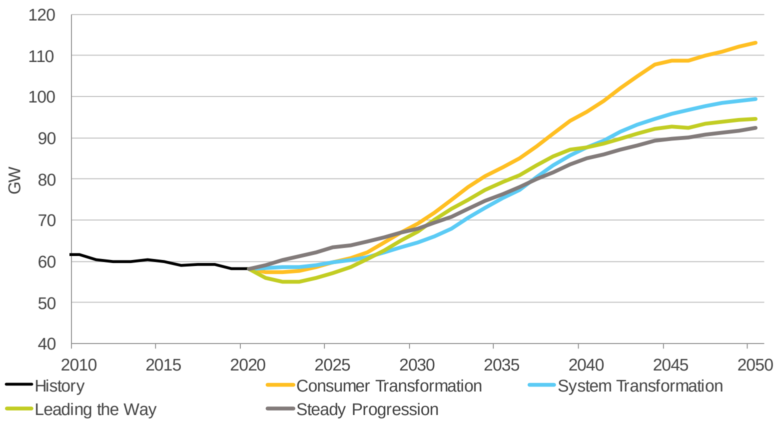
7.5.1.3 District heat systems are anticipated to capture process heat from thermal power plants, critically these plant will need to be low-carbon themselves, drawing back to electricity demand through hydrogen electrolysis: the increasingly critical energy vector. [7, pp21&24].

7.6 Future electricity peak demand

7.6.1.1 The future daily profile of electricity demand is less easy to forecast, but estimated peak demand remains a key determinant of required installed generation capacity.

7.6.1.2 Figure 7-2illustrates the potential peak demand for GB power (using NGESO's Average Cold Spell methodology) to 2050. In the four scenarios, peak demand is anticipated to range between 59 GW and 67 GW by 2030 (for comparison, 2019: 59 GW); between 71 GW and 83 GW in 2040, and between 76 GW and 96 GW in 2050. Despite there being anticipated to be a drop in peak demand until 2025 in most scenarios, all scenarios show an increase in peak demand thereafter, driven by underlying industrial and commercial demand growth as well as the electrification of heating and transport.

Figure 7-2: Future net peak electricity demand [94, Figure FL.4].



7.6.1.3 EVs and Hydrogen vehicles require the deployment of significant additional electricity generation capacity, and may also act as integration measures for all renewable and baseload generation technologies, capable of shifting load from when demand is high, to periods where supply is high. Until recently, system peak demand has been expected to reduce in the future, with Vehicle-to-Grid (V2G) technologies working alongside enormous national-level batteries, helping keep peak electricity demand down as well as providing income for vehicle owners. More recently, NGESO (in particular) have updated their analyses to incorporate consumer behaviour, noting that many cars will be on the road returning children from school and workers to their homes, during peak periods. V2G is less likely to be a significant contributor to peak demand shaving than previously thought. Tesla's Elon Musk aligns with NGESO's thinking:

> *Vehicle-to-grid sounds good but I think actually has a much lower utility than people think … Very few people would actually use vehicle-to-grid capabilities … in part because cars are not plugged in constantly.* [57]

7.6.1.4 Ofgem announced a new Strategic Innovation Fund in August 2021. The £450M fund will be deployed over five years as part of the regulated price controls for the electricity system operator, and for the network companies which operate GB's energy networks. The fund, and its source, further signals the significant and imminent changes required to continue the journey to Net Zero. Ofgem state that the fund will help GB "find greener ways to travel, and to heat and power Britain at low cost. Britain's energy infrastructure will play a pivotal role in cutting net zero greenhouse gas emissions". Growth in electricity demand through the electrification of heat and transport, and the introduction of versatile energy vectors, such as hydrogen, which will be produced with the help of low-carbon electricity generation capacity, to decarbonise industry and hard-to-reach sectors, is certain. An increase in the complexity of electricity – and energy – system operation is likely, but must be overcome in order to meet Net Zero. The Strategic Innovation Fund, and others like it, will work to ready our energy networks for the growth in low-carbon generation required to meet future estimates of electricity demand.

8 Implications for future electricity supply needs

8.1 Setting the scene on future electricity supply

8.1.1.1 To enable the Net-Zero transition, it is clear that the power generation sector must both increase in capacity and reduce in carbon intensity on an unprecedented scale.

> *[Meeting a possible doubling of electricity demand by 2050] would require a four-fold increase in clean electricity generation with the decarbonisation of electricity increasingly underpinning the delivery of our net zero target.* [18, p42]

> *We are not targeting a particular generation mix for 2050 ... The electricity market should determine the best solutions for very low emissions and reliable supply, at a low cost to consumers.* [18, p42]

> *New low carbon capacity is needed over the next decade and renewables can deliver this. As the [National Infrastructure] Commission argued in the first Assessment, due to current plant retirements, in the 2020s there will be a gap in electricity generating capacity, that needs to be filled. It must be the case that low carbon generation fills this gap. Given their short lead times, renewables are ideally placed to do this. With the exception of Hinkley Point C, nuclear power stations would likely only be able to deliver new capacity in the early 2030s. It therefore makes sense for government to take action to deploy renewables now.* [42, p10]

8.2 Future electricity supply

8.2.1.1 Each FES scenario developed by NGESO describes a possible way that the energy system may develop, based on a forecast of demand and government policy. The scenarios do not indicate forecasts of confirmed and consented generation capacities, nor do they seek to imply or impose restrictions on the capacities of generation of particular technologies which may be required, or may be delivered. The FES scenarios therefore do not imply a requirement for particular generation technologies, and nor can their datasets sensibly be disaggregated to indicate need for a single generation technology within a future system scenario. Further, the inclusion of future projects within the planning system does not also indicate a commitment by or obligation on the Applicant actually to deliver that project at all, or if it does, at a particular generation capacity[9].

8.2.1.2 In the context of Net-Zero, the FES are a useful suite of documents to understand whether particular future pathways for electricity generation will be successful from a national policy perspective. The need for more generation capacity to be built has been a consistent theme since the first FES was published in 2012.

8.2.1.3 Each year the FES scenarios have described consistently high capacities of offshore wind generation connecting to the national transmission system, on the basis of objective economic assessment of current and future costs and/or market drivers. The FES scenarios

[9] Analysis of the CfD Register shows that 16 projects with CfDs have registered a reduction to the capacity of the CfD Unit to date. They are: offshore wind: 2 projects, 76 MW reduction (11% of initial installed capacity); onshore wind: 10 projects; 66 MW (12%); biomass conversion: 1 project, 13 MW (3%); solar PV: 2 projects, 4 MW (14%); advanced conversion technology: 1 project, 3 MW (10%). Further, 6 projects have had their CfD terminated, including 4 advanced conversion technology projects, (52 MW), 1 biomass with CHP project (85 MW), and one solar PV project (12 MW). [12]

can therefore be regarded as an important point of view, which contributes to an objective assessment of the need for, and scale of, low-carbon offshore wind electricity generation developments under different future scenarios of demand and government policy, particularly within the context of Net-Zero.

8.2.1.4 The 2021 FES [94] foresees one of its four scenarios (being a scenario of steady progression rather than rapid low-carbon generation deployment) missing the legally binding national decarbonisation targets in 2050. This is the scenario with the slowest growth in renewable electricity generation capacities. All three of NGESO's 2050-compliant scenarios include the commissioning of large capacities of low-carbon offshore wind and solar power generation, among other initiatives to facilitate emissions reduction in other industrial sectors. Research by the ESC corroborates this view.

8.2.1.5 From their analysis, NGESO conclude that installed electrical generation capacity in GB (including storage and interconnectors) needs to increase from 2020's ~105 GW to between 168 and 199 GW to meet anticipated demand in 2030, this being an increase of 79 to 110 GW on existing generation capacity following the decommissioning of all but 1 GW of existing nuclear generation and the closure of all remaining coal generation (5 GW) before that date.

8.2.1.6 The most striking insight from the 2021 FES is that by 2030, over 70% of installed generation capacity must be low carbon generation in order to meet Net-Zero targets, pointing to a significant growth in low-carbon generation in the coming decade. Interconnectors are expected to contribute 10% of capacity and these will rely on our national neighbours to follow similar decarbonisation plans to the UK for their supply to be low-carbon. Only ~20% of capacity will be indigenous GB carbon-intensive generation, down from 41% in 2020.

8.2.1.7 Further, NGESO forecasts that between 305 and 357 GW of generation capacity will be required to meet demand by 2050 (continuing the increasing trend from previous forecasts), with no remaining GB operational carbon-intensive generation [94, Table SV.22], [6, Table SV.23], [56].

8.2.1.8 The FES scenarios which achieve Net Zero include offshore wind capacities of 38 – 47 GW in 2030, in 2040 68 – 83 GW in 2040, and 87 – 113 GW by 2050. In every scenario, a pathway to Net-Zero includes a significant increase of offshore wind capacity beyond that predicated in the Sector Deal, and an increase relative to NGESO's forecasts from 2020 [94, Table SV.28].

8.2.1.9 NGESO are not alone in anticipating the capacity of low-carbon generation required to meet Net-Zero. The CCC suggest that in order to meet a doubling of electricity demand from 100% low-carbon sources, by 2030 up to 60 TWh of low-carbon generation (equivalent to approximately 15 GW offshore wind capacity) will be required, on top of the offshore wind sector deal commitments [26, p155], and up to 75 GW of offshore wind could be required by 2050 [21, p23].

8.2.1.10 The National Infrastructure Commission scenarios anticipate that 129 – 237 GW of renewable capacity must be in operation by 2050, including 56 – 121 GW of solar, 18 – 27 GW of onshore wind, and 54 – 86 GW of offshore wind [42, p18].

8.2.1.11 The ESC anticipates broadly similar generation capacities. 165 – 285 GW of capacity will be required in 2050, including 33 – 66 GW of offshore wind. The ESC is more bullish on future nuclear capacity than other analyses, anticipating 20 – 38 GW of nuclear versus 5 – 16 GW (NGESO) and just 5 GW (NIC). [7]

8.2.1.12 Ofgem state that: 'The UK has made great progress in developing offshore wind, but capacity will have to increase enormously to achieve net zero' [61, p5], describing in the same document, their plans to 'Explore regulatory options to support development of an offshore grid to enable a four-fold increase in offshore wind generation by 2030' – i.e. consistent with current government policy as confirmed in the 2020 Energy White Paper [18, p45].

8.2.1.13 Many forms of low-carbon generation will be required to meet the UK Climate objectives. A diverse mix of generation is required to minimise integration costs for those times when variable technologies are not generating electricity, but this does not mean that particular low-carbon generation developments should be curtailed to promote diversity. In 2020, GB sourced 44% of its electricity from renewables, and approximately 30% from wind alone [94, table SV.23]. In both 2019 and 2020, Denmark sourced 50% of its electricity needs from renewable generation (wind being the majority contributor) [66, 99], demonstrating that high proportions of renewable generation can be accommodated within national electricity systems. GB can learn, and is learning, how to do this from other nations which are further ahead in this regard.

8.2.1.14 2021 saw the second edition of the FES since GB adopted Net-Zero legal commitments. FES 2021 analyses three scenarios under which Net-Zero emissions can be achieved by 2050, and one scenario which misses the targets. NGESO align with the Energy Systems Catapult (see Section 4.2) on the view that the 80% decarbonisation target could have been reached through multiple technology pathways, but that achieving Net-Zero requires greater action across all solutions, including broader system-wide thinking. FES 2019 concluded that action on electrification, energy efficiency and carbon capture would all be needed at a significantly greater scale than assumed in any core scenarios [56, p2], and subsequent FES scenarios have progressively borne out that conclusion. Six important predictions from NGESO's most recent analysis are that, by 2030:

- While in all scenarios, GB energy demand is expected to be lower in 2050 than 2020 (by between 42 and 57%, GB electricity demand is expected to increase in all scenarios as a result of electrification of transport & home heating, and replacement of fossil fuels with blended, gas, hydrogen or electricity. By 2050, electricity demand is forecast to increase by between 50 and 91% versus 2020 [94, Table CV.1];
- Storage and interconnection (flexibility) capacity will need to increase (from 8 GW in 2020) to 25 – 38 GW in 2030 and 47 – 71 GW by 2050 to balance supply and demand both within the GB system and across borders [94, Table SV.22];
- Due to the electrification of other sectors, peak demand[10] is expected to rise (from 2020's level of 58 GW) by 63 – 94% by 2050, even with the storage and interconnection capacities anticipated above to support "peak shaving" [94, Table SV.22];

[10] FES uses the Average Cold Spell (ACS) definition which is consistent with the treatment of demand in the electricity Capacity Mechanism.

- Therefore GB installed generation capacity will need to increase (from 103 GW in 2020) to 168 – 199 GW by 2030 to meet demand, with 69 – 75% of that capacity being low-carbon in 2030 (vs. 55% today), and 100% low-carbon by 2050;
- Installed generation capacity will need to grow even further (to 305 – 357 GW) by 2050 to meet demand, and must be 100% low-carbon to meet Net-Zero legal requirements;
- In order to meet the 'Net-Zero' target, a radical transformation to our national energy ecosystem is required, meaning even more low-carbon, wind and solar generation capacity than even the most ambitious scenarios currently envisage, will be required to meet the UK's legally binding targets.

8.2.1.15 In summary, experts have concluded, and government has agreed, that decarbonisation in the UK needs to be significantly deeper, broader and more urgent than it has previously been considered, this is evident through FES 2021 by an increase in all low-carbon metrics versus previous FES editions and in published analyses by other market experts.

8.2.1.16 A massive move to electrification will be required fundamentally to underpin broad and deep national decarbonisation, and Net-Zero requires a "system view" to be taken. This means recognising the importance of whole-system thinking in relation to the decarbonisation of non-energy sectors. Alternative energy vectors, for example hydrogen, will be of fundamental importance in the displacement of fossil fuels from industry, transport and homes. Electricity generated from low-carbon sources will be an important means of producing hydrogen.

8.2.1.17 Therefore, significantly more low-carbon generation than is operational today, from diverse sources, along with energy efficiency and electricity storage is required to meet the anticipated increase in electricity demand.

8.3 Demand response

8.3.1.1 Energy demand management, which is also called Demand Side Response (DSR) could also play an important role in the future of the energy balance of the UK. DSR is valuable insofar as it is compatible with end-use generation technologies and system-wide commercial drivers. However DSR can neither increase the total amount of electricity generated in the UK, nor reduce the total amount of electricity consumed.

8.3.1.2 Currently Industrial DSR capacity is estimated at 1.3 GW nationally [94, Table FL.9]. FES scenarios forecast between 3.3 and 5.5 GW may be operational by 2030, rising to between 6 – 16 GW by 2050. The significance of the scale of growth of DSR as an enabler of a low-carbon energy system must be viewed within the context 11 GW of coal and nuclear generation (vs. FES 2020 baseline) coming offline before 2030 and additional GB generation required to meet the demand growth as described in Section 7.3. Therefore although DSR may deliver a significant contribution to the delivery of UK decarbonisation before 2030, DSR cannot fully replace the need for new generating capacity to deliver GB's energy objectives, further underpinning the need for low-carbon generation to come to market within this timeframe.

8.4 Wider decarbonisation requires a significant capacity of offshore wind

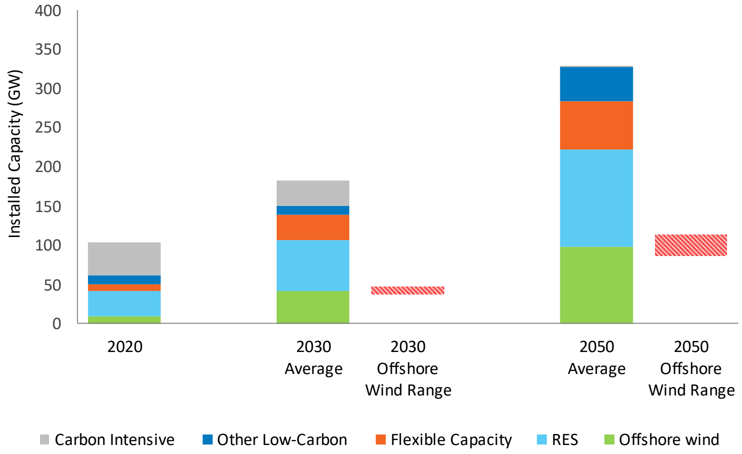
8.4.1.1 Because electricity can be generated from low-carbon technologies, the demand for electricity in GB will grow as electricity enables the decarbonisation of other sectors. The need for significant growth in new generation assets is therefore clear, not only to meet this additional demand, but also to offset the closures of many existing generation assets, either because of environmental regulation or technological lifetime limits.

8.4.1.2 Historically generation assets in GB have been called 'conventional': predominantly coal, oil, gas, nuclear or hydro-powered. They have been dispatchable assets, meaning that their output and operational schedules are controllable: electricity on demand. Generally capacity utilisations[11] have been high (>80%).

8.4.1.3 Figure 8-1 shows NGESO's analysis of how generation capacity may evolve between 2030 and 2050 to meet a growing electricity demand, and a decreasing carbon budget. As GB makes progress towards its legal decarbonisation targets through the installation of more renewable generation capacity, total installed capacity rises in proportion. This is firstly because electricity demand is increasing, and secondly because the capacity factor at renewable assets is lower than the capacity factor at conventional assets.

8.4.1.4 It is important to appreciate that of the very many possible future scenarios for future electricity demand and supply, only some will achieve Net-Zero. Some scenarios may cause cost-to-consumers to increase, while others may provide efficient and effective solutions. Government's position on the wider benefits of renewable generation is clear:

Figure 8-1: Generation capacity by technology type and amount of renewable capacity for 2030 and 2050 [94, Figure SV.22].



Increasing the amount of energy from renewable and low carbon technologies will help to make sure the UK has a secure energy supply, reduce greenhouse gas emissions to slow down climate change and stimulate investment in new jobs and businesses. [67]

8.4.1.5 NGESO data shows that offshore wind generated over 45 TWh of electricity during 2020

[11] This is usually expressed as a quotient, calculated as {Total energy generated in a year [MWh]} divided by {Maximum power output [MW] x 8760 (hours in the year [h])}

from 10.5 GW of built capacity [94, Table SV.23]. This makes offshore wind the third largest power generation technology (by output) in GB during 2020. Critically, with 40% of Europe's wind in GB waters, offshore wind is a technology with future potential, and need, for further growth. The largest power generation technology, Combined Cycle Gas Turbine (CCGT), is not low-carbon, so continued unabated gas generation is not currently consistent with Net-Zero requirements. Either the source fuel must be decarbonised (e.g. a move from natural gas to hydrogen) or CCUS must be used in order to 'green up' CCGT operations. The changing contribution of the second largest technology (nuclear) to low-carbon generation in the coming decade, is shown in Figure 5-5.

8.4.1.6 Section 5.4 describes why it is not likely that CCUS (the process to decarbonise carbon-intensive electricity generation) will play a significant role in reducing UK carbon emissions in the decade ahead, and Section 5.5 describes why nuclear generation will also not make a net positive contribution to carbon reduction over the same period. Yet Section 5.3 describes the need for urgent progress in decarbonisation. GB must therefore continue to plan decarbonisation on a conservative basis to ensure sufficient supply is built out. Significant additional renewable generation capacity is therefore required to make progress in decarbonisation, both as dispatchable low-carbon technology developments continue, and on an enduring basis, to meet foreseen electricity demand growth.

8.4.1.7 Figure 8-2 shows the evolution of carbon intensity of electricity generation under two scenarios. The green line shows forecast average GB electricity generation carbon intensity under the NGESO FES 2021 scenarios which the meet Net-Zero target. Critically, the power sector reaches net negative emissions in the early 2030s. The yellow line illustrates the importance of offshore wind to the GB generation mix. By replacing future additional offshore wind generation with CCGT generation (at 350 gCO_2/ kWh) the critical importance of additional offshore wind development to the decarbonisation of the GB electricity system becomes very clear. Without the development of additional offshore wind projects, the gap between the two carbon intensity trajectories widens through until the mid-2030s and does not close again, effectively putting a halt to further reductions in the UK's carbon emissions.

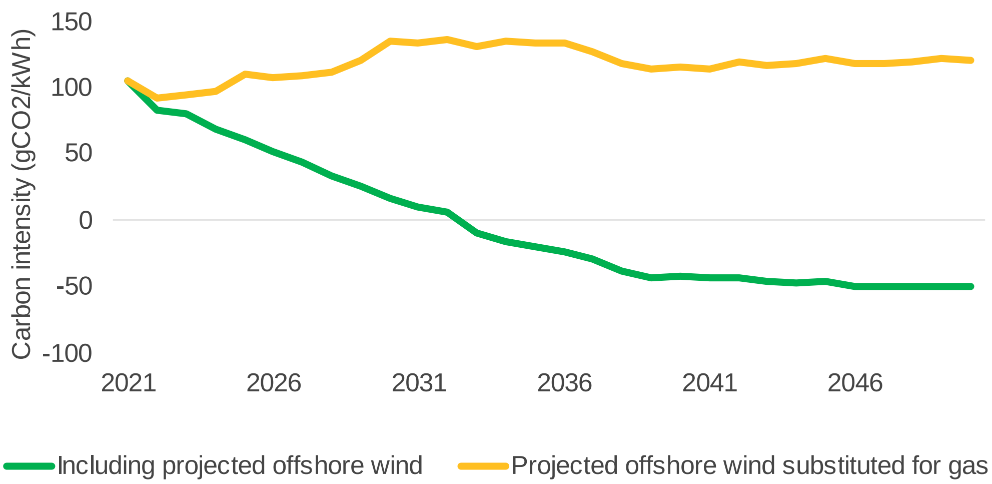
8.4.1.8 The first conclusion is therefore that the bringing forwards of offshore wind development projects should be prioritised and progressed with determined rigour and drive, to enable their timely delivery. Secondly, that the further identification of offshore wind developments and other low-carbon initiatives should be identified and progressed with urgency to ensure the carbon intensity trajectory illustrated can be achieved or bettered.

8.4.1.9 The UK requires swift and continued deep decarbonisation actions in order for it to meet its 2050 climate targets. As the leading low-carbon generation technology in GB, it is critical that offshore wind generation is permitted to continue to grow to move the country towards meeting its Net-Zero commitments.

8.4.1.10 Table 5-1 shows that GB currently has 10.8 GW of Transmission Entry Capacity already allocated to offshore wind developments with a status of 'built'. Projects totalling a further 55.8 GW have also been identified, and are listed with a status of either 'scoping', 'awaiting consents', 'consents approved' or 'under construction / commissioning' [13]. Figure 5-1 illustrates NGESO's modelling of possible commissioning dates for offshore wind projects already identified.

8.4.1.11 It is important to note that the inclusion of a project on a 'future project pipeline' – for example, a list of projects which have applied for a DCO, or the scoping / consents / construction pipeline included in Table 5-1 and Figure 5-1 – does not indicate that the project will go ahead, or if it does, at a particular generation capacity. It is therefore not the case that the ambitions of the Sector Deal, nor the newly adopted government policy, will certainly be met by those projects currently under consideration by developers. Within this context, the importance of all offshore wind projects currently under development, to the achievement of government policy and pledges, is clear. Without Hornsea Four[12], it is very possible that delivery of the Sector Deal and government's 2030 ambition will fall short.

Figure 8-2: The effect on carbon intensity, of removing additional offshore wind generation from the future GB generation mix (adapted from [94]).



8.4.1.12 It is the view of the author of this report, that if a significant capacity of offshore wind generation is not built out to a scale comparable with that in the projections provided by NGESO and others, then the UK will be highly unlikely to continue to reduce its carbon emissions over the coming decade, and ultimately meet its legally binding decarbonisation targets.

9 Decarbonisation can maintain or enhance security of supply

9.1 Setting the scene on security of supply

9.1.1.1 Decarbonisation is just one of the three pillars of GB energy policy. Low carbon generation of all forms – nuclear, wind and solar included – brings with it new challenges. Current and future energy policy and related actions must also ensure that security of supply is maintained, and that electricity is affordable for all. This chapter demonstrates how offshore wind has contributed, and will continue to contribute, to security of supply in GB.

> *The government needs to ensure sufficient electricity generating capacity is available to meet maximum peak demand, with a safety margin or spare capacity to accommodate unexpectedly high demand and to mitigate risks such as unexpected plant closures and extreme weather events.* [3, Para 3.3.2]

[12] Which holds a Grid Connection Agreement, is listed on the NGESO TEC Register [13], and which could be built out by the mid 2020s

The larger the difference between available capacity and demand ... the more resilient the system will be in dealing with unexpected events, and consequently the lower the risk of a supply interruption. [3, Para 3.3.3]

A diverse mix of all types of power generation. . . helps to ensure security of supply. [3, Para 3.3.4]

9.1.1.2 'Security of supply' means keeping the lights on and has two main components. These are:

- Ensuring that there is enough electricity generation capacity available to meet demand (adequacy); and
- Ensuring that the quality of electricity supplied to customers falls within a narrow 'quality' band during all reasonably foreseeable operational circumstances, and is resilient during rare excursions from this band.

9.1.1.3 In this section, power systems and aspects of their operation will be briefly introduced. Challenges associated with integrating renewable generators into existing systems will be characterised, and key points on the contribution of offshore wind generation to system adequacy and system operation are presented. Specifically:

- The planned development of an offshore wind farm, Hornsea Four, will contribute significant capacities of low-carbon generation to national system adequacy targets;
- The diversification of GB's electricity supplies through the commissioning of offshore wind assets (such as that planned for Hornsea Four) to the NETS, alongside other low-carbon generation technologies, provides benefits in the functioning of the NETS and ensuring power is available to consumers across the country when it is required, due to its requirement to operate within the stringent operability and control requirements of the Grid Code [69];
- Technical advances in the field of power electronics and other measures are significantly increasing the utility of power generation assets in the provision of services and protections which support grid operation [70];
- A program of grid investment and operational development by NGESO, regulated by Ofgem, is aiming for safe and secure operation of the NETS at zero-carbon by 2025 [56, p1]; and
- By including the possibility of developing Energy Balancing Infrastructure within the scheme, the Applicant will be able to bring forward and install technological solutions to aid the integration of high levels of renewable power generation into the electricity market, potentially including hydrogen or battery energy storage system technology.

9.1.1.4 To provide appropriate context and understanding we set out in brief an introduction to a number of high-level concepts of power system operation.

9.2 An introduction to power system operation

9.2.1.1 Power systems connect supply (sources of power, largely generators) to assets which demand power (industrial, commercial or domestic customers). Power systems are complex; yet they must be designed and operated safely, securely and economically.

9.2.1.2 Governments define policy to ensure that there is sufficient generating capacity[13] available to meet maximum expected demand. This is called adequacy.

9.2.1.3 Key power quality characteristics (including frequency, voltage and power shape) must be controlled in order to maintain the synchronicity of all assets. NGESO define this topic area as system operability, specifically: "the ability to maintain system stability and all of the asset ratings and operational parameters within pre-defined limits safely, economically and sustainably" [71, p5]. Protecting the synchronicity of a system when an asset operates outside of normal expected parameters is also important, and individual transmission-connected generators, such as is planned at Hornsea Four, must maintain their own synchronicity with the system.

9.2.1.4 NGESO also ensure that power demand, or load, and power supply, remain balanced at all times. Balancing requires the right generating assets to be connected and disconnected to/from the right power levels, and at the right time. This can sometimes be at short notice, in response to emergent (fault) conditions. NGESO call those services which support NETS stability and operability are called Ancillary Services.

9.2.1.5 The voltage level on the system is dependent on the type and quantity of generator and demand load connected to the system at the time. Over-volts occur when power demand is low, and load is too light. Voltage collapse occurs when load (particularly from heavy inductive machinery) is too high. Reactive power helps to maintain voltage levels, and its provision by generators is a mandatory service for Transmission-connected generators.

9.2.1.6 System frequency must also be maintained[14]. Unless generation is scheduled to match demand, when system load increases, system frequency dips; and when system load is lightened, frequency increases. Because demand fluctuates continuously through the day, frequency must be continuously managed, and generators must therefore provide frequency response ("FR") services. Under FR, generator output is raised on receipt of a signal from the system operator of a falling frequency; and reduced on receipt of a signal from the system operator of a rising frequency. Due to the impact of FR on MW output[15], generators which are able to provide FR will usually determine the price they would accept to provide the service.

9.2.1.7 If a sudden and unexpected disconnection of either demand or generation occurs, frequency may change rapidly. System inertia, a measure of the kinetic energy stored in rotating machines which are directly connected to the NETS, helps protect the system against rapid frequency changes. A system with high inertia is less likely to experience rapid system changes and will therefore be more stable, reducing the risk of faults escalating into wide-ranging effects on generators and customers [71, p43]. An important metric is the rate of change of frequency, ("RoCoF"). System inertia is a phenomenon uniquely important to NETS because of its relatively low levels of interconnection to other, larger, electricity systems such as is the case, in particular, across Europe.

[13] i.e. The maximum achievable level of power generation which may be connected to the NETS.
[14] The NETS operates at a nominal 50 Hz.
[15] Output remains the main source of generator income.

9.3 Operating high-RES electricity transmission systems

9.3.1.1 The integration of RES and their likely effect on electricity transmission systems were first discussed in a 1991 paper by M.J. Grubb [72]. He foresaw that capacities of renewable generation will not be limited; and therefore that "proper management" of those capacities (alongside any remaining conventional capacities) must be carried out in order to maintain a stable electricity system. This topic is not new. The electricity industry has, over the last 30 years, implemented new processes and technologies, and stable operation of electricity systems is being achieved with higher shares of renewable generation on an increasingly regular basis. For example, in both 2019 and 2020, Denmark sourced over 50% of its electricity needs from renewable generation [66]. And in the UK, renewables' share of electricity generation was 44% during 2020 [94, Table SV.23]. These are statistics which demonstrate that high proportions of renewable generation can be accommodated within national electricity systems.

9.3.1.2 In foreseeing a need for maintaining the quality of electricity supplies, Grubb identified important considerations for system operation[16], and explains how an increase in renewable generation influences each one. He sees the critical issue as being the determination of how important each ancillary service becomes in a future energy system, and how capable the generation assets connected to that system are to provide that service.

9.3.1.3 The activities associated with integrating renewables into the GB electricity system will increase with their penetration [73, p2]. Energy balance must be managed at all times; and as renewable capacity increases, more services will be required to regain supply / demand balance and retain system control, particularly when demand is either very high or very low.

9.3.1.4 Importantly however, the dynamic behaviour characteristics for a high-RES system are well understood. NGESO's System Operability Framework (SOF) [74, 75] describes these in specific relation to the GB electricity system.

9.3.1.5 Further, technological advance, in particular the introduction of power electronics into generating assets, is increasing the ancillary services and system stability services available from users of the electricity system, for example, by improving an asset's fast response to system frequency changes, and their ability to withstand periods of system instability without disconnecting.

9.3.1.6 System stability services are already being provided by fast response batteries, for example NGESO's Enhanced Frequency Response service, tendered for in 2016 and still operational in GB as part of NGESO's new frequency response product suite. More recent advances have been made in the conversion of thermal and pumped storage assets into synchronous inertia providers (see for example: https://www.nationalgrideso.com/transmission-constraint-management?market-information).

9.3.1.7 Further, the installation of power electronics at low-carbon generation assets enable them to provide important system stability services [70]. By reprogramming the digital power inverters attached to wind turbines, they can emulate the behaviour required by the System Operator. Offshore wind farms under development are well placed to incorporate power

[16] Rate of change of frequency; system operational control and fault containment; and reserve operation.

electronics into their designs, so as to be able to provide important stability services through their operational lives.

9.4 Connecting generators to the power grid

9.4.1.1 The electricity system in GB operates at two levels: the high-voltage NETS, and the lower-voltage Distribution Networks. The NETS is mainly made up of 400 kV, 275 kV and 132 kV assets connecting separately owned generators, interconnectors, large demands and distribution systems, and currently consists of approximately 4,500 miles of overhead line, 1,000 miles of underground cable and 350 substations. Applications for connection to the NETS are assessed through the first-come-first-served 'Connect and Manage' process.

9.4.1.2 Connect and Manage offers are given to those customers who request a connection date ahead of when any identified wider transmission reinforcement works can be completed. The connection agreements contain the requirement for derogation against the National Electricity Transmission System Security and Quality of Supply Standards (SQSS) which, once approved, allows for a connection to be made ahead of those wider transmission reinforcement works.

9.4.1.3 Wider transmission reinforcement works may be required to ensure that, once connected, electricity can flow from generators to where it is needed without constraint or hindrance. Generation connections close to demand centres (e.g. large cities or industrial areas) require the bulk transfer of power over shorter distances and therefore attract both capital and operational cost benefits when compared to generation connections far away from where the power is needed. However, with an ever-growing share of renewable generation capacity on the NETS, the bulk transfer of power over long distances remains vitally important, in order to keep lights on across the whole country when renewable generation output is high only in one area.

9.4.1.4 Each year, NGESO publishes a Network Options Assessment report, which recommends investments to reinforce the NETS. Their recommendations will allow them to manage the future capability of the GB transmission network against an uncertain energy landscape over the coming decades In 2019, they recommended £59.8M of immediate investment in order to progress projects costing £5.4B [76, p4]. By 2021, immediate investment recommendations had increased to £183M on projects costing £13.9B [102]. These costs will ultimately be recovered from consumer bills. As such it is in the interests of consumers to maximise the efficiency and effectiveness of existing and new transmission connections, and ensure value for money is secured for any wider reinforcement works which may be required as a result of new locations.

9.4.1.5 Grid connection is an important aspect of generation project timescales and costs. The selection and utilisation of efficient grid connections in beneficial locations allows projects to come forwards at lower cost of generation and lower overall cost to consumers

9.5 Centralised and decentralised generation

9.5.1.1 In all 2021 FES scenarios, decentralisation of generation is expected to increase, driven by the growth in smaller scale renewable generators. Many small generators do not connect directly to the high voltage transmission system, but rather to the medium or low voltage distribution systems [77, p34]. Currently 30% of all generation capacity is connected to the distribution networks and FES scenarios project that by 2050, the proportion may develop to between 25% and 44% [94, Table ES1]. Distribution networks operate at a lower voltage than transmission networks, so generators which connect to these systems must have smaller capacities than those which connect to the NETS. As a consequence, in order to connect the same total generation capacity, more connections would be required at the distribution network level (at a potentially greater overall cost to consumers) than would be required directly into the NETS.

9.5.1.2 However distributed generation grows, the replacement and growth of transmission connected assets is also foreseen. Although distributed generation will contribute to meeting carbon emissions targets, increasing energy security and will lead to some reduction in demand on the main generation and transmission system, government does not believe they will replace the need for new large-scale electricity infrastructure to meet UK energy objectives. The recent implicit market preference for decentralised generation connections should be understood in the context of GB's national electricity system, with 72 GW of generation currently connected to the transmission network and 31 GW to the distribution network. FES 2021 scenarios [94] show that capacity connected to the distribution networks is likely to grow at similar or higher levels than capacity connected to the transmission network. In 2050, between 2.7 and 4.5 times 2020's distributed generation capacity may be connected to distribution systems, while the multiplier for transmission-connected assets ranges between 2.5 and 3.2. NGESO scenarios indicate a total of 178 – 233 GW capacity installed at the transmission connected level by 2050.

9.5.1.3 Distribution networks were originally designed predominantly to transport bulk power to consumers. They were not designed to connect significant capacities of electricity generation. By virtue of their role in transferring power from the bulk NETS to businesses, built facilities and houses, many distribution networks are located in built up areas, away from areas of large natural resource potential. Geographical and technical constraints may therefore arise as generators continue to be connected to these networks, applying upward pressure to the costs and durations required to grant a connection agreement. This may materialise as significant cost, timing and complexity considerations both for asset developers as well as for consumers who ultimately pay for the developments and the operation of the complex distribution systems which result. Further:

> *Government does not believe that decentralised and community energy systems are likely to lead to significant replacement of larger-scale infrastructure. Interconnection of large-scale, centralised electricity generating facilities via a high voltage transmission system enables the pooling of both generation and demand, which in turn offers a number of economic and other benefits, such as more efficient bulk transfer of power and enabling surplus generation capacity in one area to be used to cover shortfalls elsewhere.* [3, Para 3.3.29]

9.5.1.4 NGESO has also made many public statements on their support for the connection of electricity generation technologies which provide a diverse energy mix to ensure that they can continue to manage supply and demand, for example [56, 78]. In conclusion, the need for distribution connected generation is in addition to, not instead of, the need for additional transmission connected generation; and therefore the development of distribution connected generation will not do away with the need for further transmission connected capacities. As such, Hornsea Four will be well placed to support grid adequacy through its proposed transmission network connection.

9.6 Transmission connected generators connect transparently to electricity systems

9.6.1.1 As previously described, large generating assets are connected to transmission systems and many smaller generators are linked either to customer connections or distribution networks. Some of the most relevant differences between transmission- and distribution- connected generator characteristics are listed in Table 9-1.

9.6.1.2 Distribution-connected generators also contribute to meeting national demand, but because of the way they are connected, they effectively self-dispatch when they are available and offset national demand, thereby reducing the transmission demand level which transmission-connected assets must meet. The connection level of an asset impacts the benefits it brings to bill payers. Four major considerations are:

- Transmission connected assets provide visibility of their expected generation to the national energy market and NGESO as part of their licence to operate. This increases transparency in the market and allows sensible economic decisions to be made by all market players, including NGESO, in both planning and operational timescales to ensure that power demand and system security needs are met with the least possible cost;
- Transmission connected assets are required to be available for instruction by NGESO. They are required to participate in the Balancing Mechanism (BM), making their flexibility available (at a transparent and cost-reflective price) to ensure that supply and demand remain balanced at all times. By contrast, distribution assets are not required to do this, although voluntary balancing markets are currently under development for smaller assets at the distribution level;
- While transmission systems have historically been designed to allow for the connection of large generating assets, distribution systems have not. Connecting generation assets of any meaningful size to distribution systems is becoming more difficult and more expensive;
- The mandatory requirements for a generator to connect to the NETS include minimum requirements for fault protection as well as system ancillary services (e.g. Obligatory Reactive Power Services). Distribution connected assets have different fault protection requirements (which are harder to enforce) however access to system ancillary services is expected to grow into the future. Transmission-connected assets are therefore differentiated in that they are de facto required to support system operation in many ways as part of their connection agreement.

Table 9-1: Characteristics of transmission- and distribution-connected generators [Author analysis]

	Transmission	Distribution
Description	Connected to NETS at high voltage	Connected to distribution network at lower voltage (distributed) or into end use customer systems (micro). Collectively called Distributed Generation

	Transmission	Distribution
Size	Typically large (100s of MW).	Typically small (<30 MW) to very small (single kW).
Technical Compliance	Required to conform to regulations and standards for critical service provision and response characteristics including reactive power, frequency response and fault ride-through.	Minimum technical thresholds are not as stringent but are increasing as a result of system interconnection requirements. Conformity with required standards may be harder to enforce.
Dispatch	Centrally dispatched by NGESO with known reliability	Generally locally dispatched with unknown reliability; outside of the direct control of NGESO.
Measurements	Metered to a high degree of accuracy, forecast output signalled to NGESO.	Largely unmetered, indications of availability, forecast output not required to be provided to NGESO

9.6.1.3 Decentralisation is not in itself a strategy or a requirement of the energy system, but is a trend which will go some way to delivering a flexible, low-carbon and affordable energy system. Continued operation of the NETS however does remain an important policy to maintain inter-regional connectedness and support the meeting of national demand from geographically disparate sources [21, p182].

9.6.1.4 Furthermore, by connecting more assets at the distribution level, less power flows on the transmission system, meaning that the unit cost of running the GB NETS increases. Electricity consumers, either directly or indirectly, pick up costs through their energy bills, related to market inefficiencies, economic decision making, asset investments, balancing actions and transmission and distribution system enhancements.

9.6.1.5 The interaction of embedded generation with the balancing of the transmission network is complex, which is one reason why it is important to maintain diversity of generation assets across technology choice, scale and connection voltage. The proposed Hornsea Four development contributes to that diversity by replacing closing transmission-connected assets, while transparently conforming to Grid Code operability requirements.

9.7 Offshore wind supports security of supply

9.7.1.1 A long-standing challenge to the ability of wind generation to play a significant role in electricity supply relates to the uncontrollable nature of the weather. The variability of wind generation can be mitigated by developing larger generation capacities (to maximise output during periods of low wind); by connecting assets to different parts of the NETS; by developing projects with complementary profiles (for example solar: see below); or by developing integration technologies (for example, battery storage or participation in the hydrogen economy). There are a number of other technologies which can be used to compensate for the intermittency of renewable generation, such as electricity storage, interconnection and demand-side response [3, Para 3.3.12].

9.7.2 Important considerations when introducing RES to power systems

9.7.2.1 Ueckerdt et al [16, p2] describe important considerations for the introduction of RES to power systems. These are described in Table 9-2.

Table 9-2: Complexities associated with renewable energy source variability in power systems [16, p2]

	Transmission	Distribution
Uncertainty	Weather forecasts incur an inherent unpredictability, bringing uncertainty to both demand and supply sides of the power-balance equation.	Until recently, power cannot be economically stored. Therefore, balancing activities will grow as renewable generation capacities increase.
Local Specificity	Renewable assets must be built to complement the local environment, in order to maximise yield.	A localised preference for most suitable technologies will emerge, diversity should be built in where possible.
Variability	While weather forecasts incur uncertainty, the weather itself is also variable.	Over timescales from hours to seasons, generation from renewable assets may be very different. A larger portfolio of RES will provide a larger dependable power level than a smaller portfolio.

9.7.2.2 Uncertainty may manifest in that the level of the demand or supply of power may be higher, or lower, than was expected. Yet it is a fundamental property of all electricity systems that demand and supply must be balanced at delivery. Improvements in demand and supply forecasting would help minimise balancing effort, and 'integration measures' are working as part of, and alongside renewable generators to provide necessary upward and downward regulation.

9.7.2.3 An example of local specificity is that South East England has a higher potential for plentiful solar generation because of its high irradiance levels than the South West, which may be better suited to onshore wind generation.

9.7.2.4 Variability is best described by the difference between summer and winter power demand or supply. Generation variability is broadly forecastable. In order to improve the likelihood of being able to ensure system adequacy from renewable generators in all but the most unlikely of meteorological situations, a large portfolio of interconnected assets from as broad as possible a range of technologies and geography may be beneficial. Hornsea Four is an important part of the growing offshore wind generation portfolio, whose dependable output is growing (see Section 9.7.3.1).

9.7.3 The location of Hornsea Four

9.7.3.1 Offshore wind developments in GB are permitted only in zones which have been identified and allocated (under a Zone Development Agreement) to potential developers by The

Crown Estate[17]. Offshore wind generation schemes can only be developed through the mechanism put in place by The Crown Estate for leasing areas of the seabed in a structured and timely way. Further detail on the process of zone identification used by The Crown Estate, and the history of zone level planning within the former Hornsea Zone, can be found in ES Site Selection and Consideration of Alternatives.

9.7.3.2 The Hornsea Four array area is a part of the former Hornsea Zone, which was identified in 2009 by The Crown Estate as one of nine zones for Round Three offshore wind farm developments. The timings of subsequent rounds (The Crown Estate anticipate Round 4 rights could be awarded in 2021 with projects becoming operational in the late 2020s [79, p7]) mean that undeveloped array areas within the Round 3 (former) zones are the only areas currently available for developers of offshore wind projects to propose projects capable of delivery in the early to mid 2020s.

9.7.3.3 The proximity of Hornsea Four to the other three Hornsea array areas (all four are located within the former Hornsea Zone) means that the weather conditions are likely to be similar across all, and therefore generation patterns may be similar across all array areas. The development of all array areas within the former Hornsea Zone is important because of the significant low-carbon electricity which will be generated from the Zone (which otherwise would not be).

9.7.3.4 The grid connection route proposed for Hornsea Four, connects to the NETS in Yorkshire. This is different to Hornsea Project One and Hornsea Project Two, which connect to the NETS in Lincolnshire, and Hornsea Project Three, which will connect to the NETS in Norfolk. Diversity in grid connection points for these four wind developments supports the operation of the transmission circuits in and around the local areas by providing more routes for power generated in the former Hornsea Zone to flow to where it is needed and minimising the possibility of curtailment due to a grid constraint during periods of high wind.

9.7.3.5 Full development of the Hornsea Four array area through the Hornsea Four project, is an important part of delivering GB offshore wind generation at the capacities anticipated to be required to meet the UK's Net-Zero commitments. Hornsea Four will make a significant contribution to meeting the target capacity in the timeframe required are therefore should be considered as both necessary and urgent.

9.8 The system adequacy of offshore wind

9.8.1.1 System adequacy is primarily managed through the GB Capacity Market. In return for capacity payments, eligible assets agree to generate at or over a minimum commitment (their 'de-rated capacity) whenever NGESO (subject to a prescribed process) determine that additional generation output is required in GB in order to "keep the lights on." Wind and solar technology are now included within the GB capacity market [80] and onshore wind and solar will be reintroduced to the Contracts for Difference mechanism in time for Allocation Round 4 (at the time of writing, anticipated in late 2021). While the Capacity Market is not open to assets which already hold CfD contracts, the inclusion of renewable generation technologies in the Capacity Market underlines the contribution renewables can make to system security: 'The system is typically better off with intermittent capacity than without

[17] The Crown Estate is the landowner of virtually the entire seabed out to the 12 nm territorial limit, and has rights under the Energy Act 2004 to issue licences for offshore wind development beyond the territorial waters limit and within the UK Renewable Energy Zone (An area of the sea, beyond the UK's territorial sea, which may be exploited for energy production)

it – wind farms, for example, can make a contribution to overall security of supply' [81, p114]. It should be noted that renewable assets also already participate in capacity mechanisms in other highly volatile electricity markets, such as Ireland's Single Electricity Market, and in parts of the US.

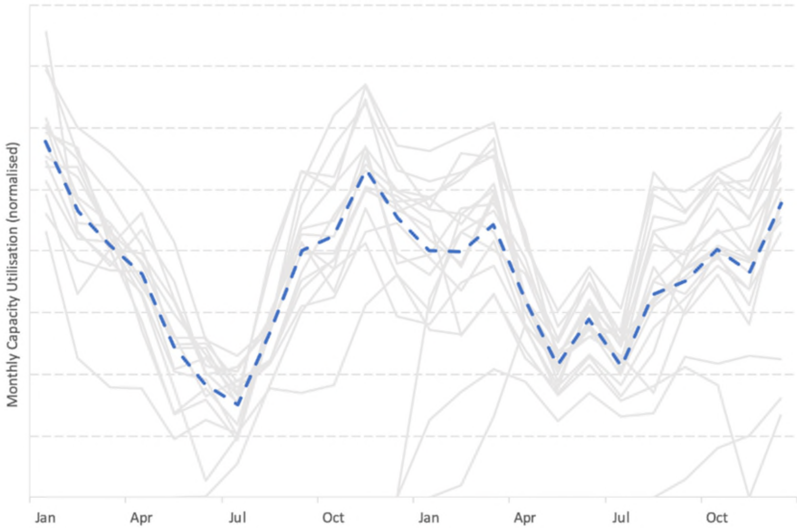
9.8.1.2 By measuring the capacity utilisation of a set of generating assets over a month, the variation in delivered generation from month-to-month as a proportion of installed capacity, can be calculated. Stable capacity utilisation (here called Generation Dependability) is important, because it relates to the reliability of, and therefore NGESO's ability to depend on, forward forecasts of generation outturn. At the macro level, a greater reliability of generation outturn allows for a more efficient and targeted asset development program to be rolled out; and lower requirement for (fossil-fuelled) backup plant (the "troughs" in Figure 9-1 are less pronounced), without creating excess generation capacity.

9.8.1.3 Figure 9-1 displays this metric for GB offshore wind generation through 2018 and 2019, expressed at a monthly level. It shows that each wind farm has its own generation profile, but that Generation Dependability is improved when measured at the fleet level, rather than for each individual asset (i.e. the blue dashed line does not go as high, nor as low, as the individual grey lines). An Imperial College expert economic analysis of whole system costs of renewables agrees: they show that the integration costs of RES fall on an absolute basis, as capacity increases from 10 GW up to 50 GW [82].

9.8.1.4 The National Infrastructure Commission also commissioned a whole-system cost analysis, the results of which were published in 2020 [30]. NIC's analysis complements that of the Imperial College team, suggesting that: "that there is no material cost impact, either over the short or long term, of deploying renewables faster. Renewables are now the cheapest form of electricity generation due to dramatic cost reductions in recent years."

9.8.1.5 Developing a generation portfolio with different renewable sources will also contribute to managing the generation dependability of intermittent generators on a national level. Excess generation may require curtailment and economic inefficiency (the "peaks" in Figure 9-1 are also less pronounced), and integration measures are expected to be developed to make use of any excess generation which occurs.

Figure 9-1: Generation dependability for GB's offshore wind portfolio. The grey lines show the traces for individual wind farms, and the dashed blue line shows a normalised average (calculated over commissioned assets only). [Author Analysis].



9.8.1.6 Therefore, it can be concluded that although individual offshore wind farms are variable generators, the generation dependability of the technology class is more stable, especially as the UK's offshore wind fleet expands to new areas of the sea. There are a number of integration measures available today to help balance electricity generation from variable generators onto the grid to meet demand, and to ensure that the best use is made of low-carbon electricity when it is being generated in oversupply. These measures include increasing the capacity and geographical reach of offshore wind generation; developing other assets with complementary seasonal generation profiles; and managing shorter-term intermittency through storage or other measures. Offshore wind is an important asset class which is needed to contribute to a required level of generation adequacy and generation dependability within the GB energy system without incurring excessive capital spend, nor causing significant integration costs.

9.9 Hornsea Four will support GB electricity system adequacy and dependability

9.9.1.1 Innovation in generation must not be allowed to challenge security of supply, but a lack of innovation in generation must not be allowed to put decarbonisation at risk. Moreover, whilst the promise of a single saviour technology is exciting, few market commentators or participants have faith in the ability of a single new technology to bridge the energy gap, but many experts are active supporters of harvesting the UK's rich wind resources.

9.9.1.2 The UK has substantial renewable energy resources, including 40% of Europe's wind resource [3, Para 3.4.3]. This resource must be harnessed to decarbonise our economy. Moreover, in Section 8.4 it was demonstrated that without offshore wind, UK would not meet its decarbonisation targets. Section 9.8 showed an analysis of the generation dependability of offshore wind as a technology class, and Section 9.6 described the measures required of offshore wind to support system operability due to its connection to the NETS.

9.9.1.3 Connection to the transmission system is of significant importance, enabling an unencumbered and efficient transfer of bulk power across the country, in order to supply electricity whenever and wherever it is needed.

9.9.1.4 Global expertise in the operation of electricity systems with high proportions of RES is growing. Technologies which help the integration of renewable assets to the grid are being developed and are already in operation in the UK. Offshore wind assets are increasingly able to provide important system services themselves, and integration assets (such as batteries) are being deployed to do the same, as well as to manage short-term supply / demand volatility. Ofgem's new Strategic Innovation Fund seeks to "drive big ideas that accelerate the transition to an emissions-free energy system and at the same time help to position the UK as a world leader in energy innovation" [98].

9.9.1.5 Growth in offshore wind capacities, and other renewable technologies, is expected to improve the dependability of those assets as a combined portfolio, and this is expected to reduce further any integration costs associated with such growth.

9.9.1.6 Hornsea Four, if approved, would contribute to an adequate and dependable GB generation mix, through enabling the generation of more low-carbon power from indigenous and renewable resources. Therefore, the approval, construction and operation of Hornsea Four will make a significant contribution to the UK's energy security and decarbonisation needs

10 Offshore wind is economically efficient in GB

10.1 Setting the scene on economic efficiency

10.1.1.1 The third pillar of GB's energy strategy, is economic efficiency.

> *Most renewable energy resources can only be developed where the resource exists and where economically feasible.* [4, Para 2.5.36]
>
> *The UK has 40% of Europe's wind resource* [3, Para 3.4.3]
>
> *Analysis [commissioned by the National Infrastructure Commission] suggests that there is no material cost impact, either over the short or long term, of deploying renewables faster. Renewables are now the cheapest form of electricity generation due to dramatic cost reductions in recent years. Cost reductions have been greater than was predicted in 2018 when the Commission made its recommendation on what level of renewable generation the government should be targeting.* [30, p9]

10.1.1.2 This section discusses broad principles of economic efficiency, by explaining how the GB electricity market operates and demonstrating how competitive CfD wind assets are because of recent gains in experience, technology and scale.

10.2 An introduction to pricing electricity in the GB power market

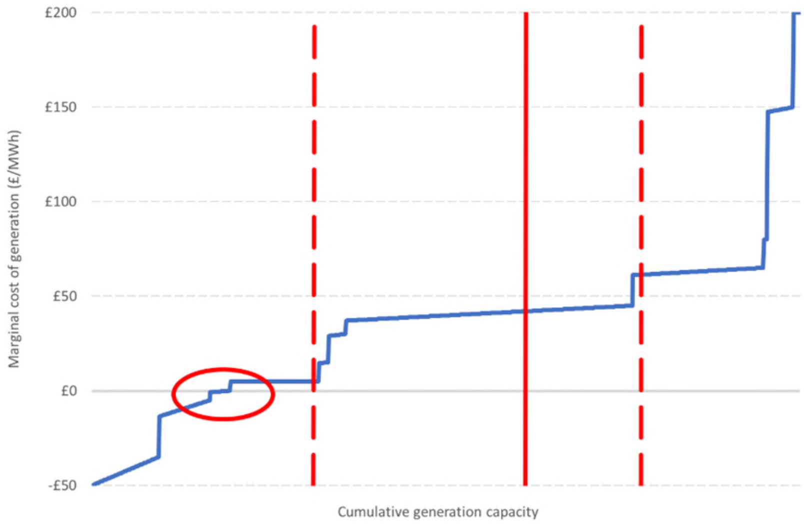
10.2.1.1 In the GB power market, generators schedule themselves to generate in response to whether a market price signal for a specific period is above or below their marginal cost of generation[18]. Each day is subdivided into 48 half-hour periods (Settlement Periods) and power is traded ahead of delivery for these periods, or continuous groups thereof, from just 90 minutes ahead, up to months or even seasons ahead. Typically, wind farms have low or zero marginal costs and therefore generate as much as they are able to, when they are available (i.e. whenever the wind is blowing). Because of the variable nature of the wind, they also tend to trade on the near-term power markets, therefore much of their impact on power price is felt in the few days close to delivery. Thermal and hydro plants have higher marginal costs (relating to the cost of the fuel they are converting into that additional MWh), therefore will generally only when the market is providing a higher price signal. They may also trade power and fuel costs further ahead in order to lock in an income. All generators produce active power (MWs), and to balance the electricity system, the active power generated must meet the system load at all times. If wind farms are generating electricity during a settlement period, then less electricity is required from plants with more expensive marginal costs, therefore the price of electricity for that settlement period reduces.

10.2.1.2 This market mechanism is illustrated in Figure 10-1. The blue line, increasing from left to right along the x-axis, represents the marginal cost of generation in GB at each level of demand. As demand increases, more expensive supply must be scheduled into the market. This is represented by the three red lines. At a mid-level of demand, the solid red line crosses the blue line at about £45 / MWh. This becomes the price of power. If demand falls (e.g. to the left-hand dashed red line), less plant is required to run to meet demand, therefore the marginal cost of the most expensive asset required to run to meet demand is lower.

[18] The cost of generating an additional 1 MWh, usually including variable fuel and transmission costs.

Therefore the price of power reduces (here, to about £10 / MWh). Conversely, as demand increases, (e.g. to the right-hand dashed red line) assets with higher marginal costs of production are required to run; therefore the price of power increases (in this example, to about £65 / MWh).

Figure 10-1: Representative marginal cost stack for the GB electricity system. [Author analysis]



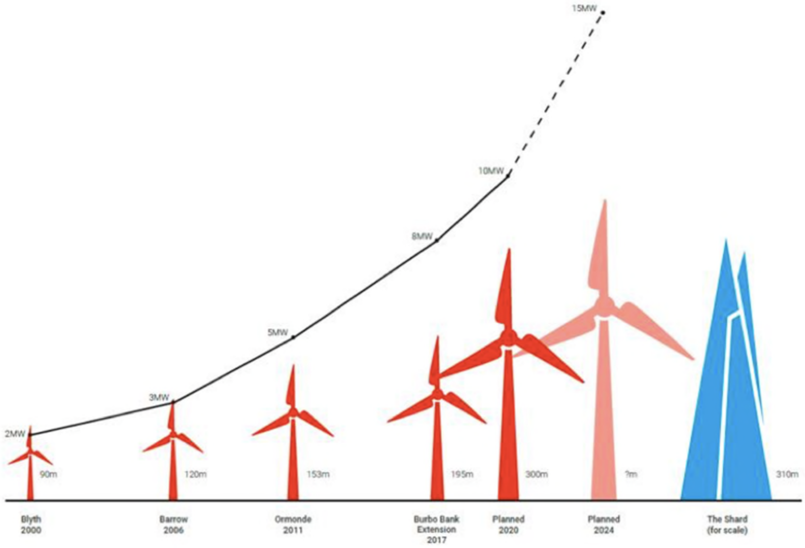
10.2.1.3 Critically, the blue line in Figure 10-1 also varies for each half hour settlement period, as generating assets become available or unavailable due to outages, breakdowns or, critically, more or less wind or sunshine is expected or experienced. Therefore as more electricity is generated by wind, the blue line within the red ellipse (around a zero marginal cost of power) will stretch horizontally, and as a result, the blue line slides to the right for all higher levels of demand. The marginal cost of production to meet demand over these periods will therefore be lower and as a result, the traded price of power will be lower. By running this type of analysis over every settlement period over the future trading horizon, it is possible to derive a view of the price of power for the next week, month, quarter or season. The conclusions are the same though: increasing the capacity of renewable assets in GB reduces the traded price of power. This demonstrates that offshore wind power reduces the market price of electricity in GB. The effect is not limited to GB. A 2018 paper by Energy Institute of Haas, 'Setting with the Sun', describes a quantitative analysis of the impact of deep solar penetration in California, an historically conventional generation market. The paper concludes that renewable investment has had a significant impact on power prices, and appears to be responsible for the majority of price declines over the last half-decade in California [83, p26].

10.3 Levelized cost of offshore wind generation

Technological advances in wind generation are unfolding, although the scope is limited by the specific nature of wind turbines. The blade design, the steel in the supporting structures, and the efficiency of the conversion to electricity are all areas for incremental improvements. Given that wind is a small-scale and low-density form of generating electricity, many of the cost reductions have come from the logistics and maintenance, especially offshore, and new designs of floating platforms add a further opportunity. Although incremental, the cost reductions have been dramatic. [81, p67]

The market mechanisms described in Section 10.2 only reduce the price of power if wind projects come to market, or if developers believe they are able to make reasonable returns on their investments. The cost of wind generation is an important enabler of offshore wind development. Wind turbines have got bigger and are being grouped in larger populations to increase the size of wind farms. See Figure 10-2. As a consequence, offshore wind is now a leading low-cost generation technology (see Figure 10-3).

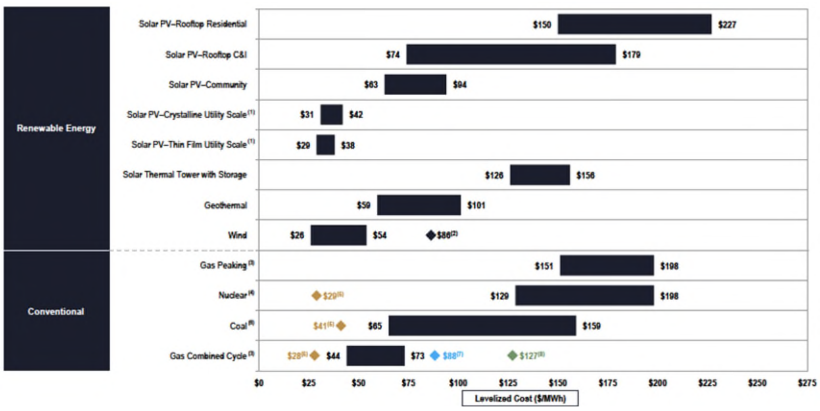
Figure 10-2: The generation capacity of offshore wind turbines has increased significantly since 2000 [9].



10.3.1.1 An important measure of the lifetime cost of wind generation, is its Levelized Cost of Energy (LCOE). LCOE is calculated using a discounting methodology, and is a measure of the lifetime unit cost of generation from an asset. Critically this allows all forms of generation to be compared with each other on a consistent basis. Lazard [10], albeit focussed mainly on the US market, is a globally recognised source of such comparative analysis. The most recent revision of their analysis, published in October 2020, illustrates that wind power is already more economically attractive than all other existing forms of generation, and is matched only by utility scale solar PV.

10.3.1.2 This comparison is presented in Figure 10-3, with the range representative of different complexities of technical solution.

Figure 10-3: Unsubsidised levelized cost of energy comparison [10, p2]



10.3.1.3 Closer to home, the NIC's current view is that RES represent a most likely low-cost solution for GB electricity generation, over large-scale conventional investments:

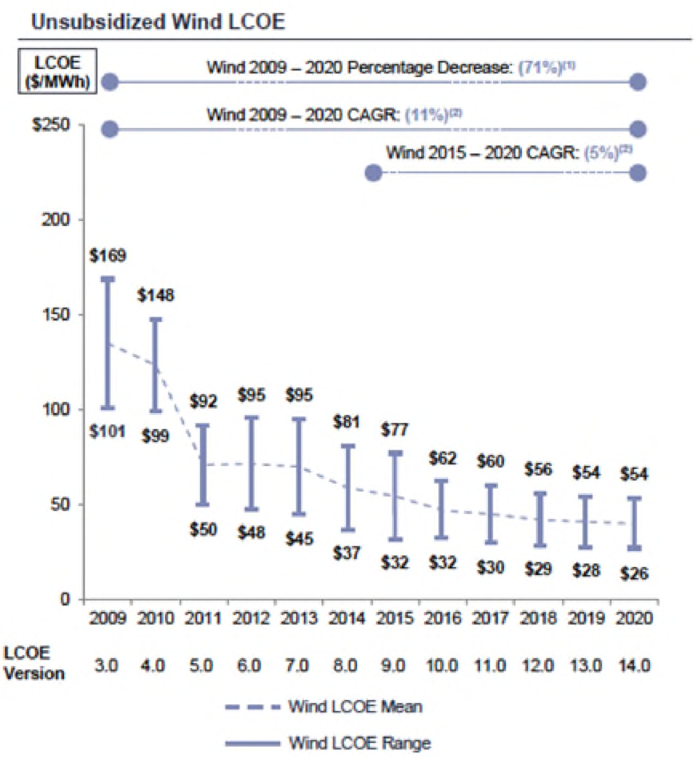
More renewables do lead to more money being spent to match supply and demand: a *system with 90 per cent renewables is estimated to cost up to £4.5 billion more per year to balance. But cheaper capital costs are estimated to offset this within the costs for the overall system.* [37, p39]

10.3.1.4 Wind costs are driven by capital infrastructure, development and integration costs, and lifetime O&M. Economies of scale and technological advances have reduced the costs of wind turbines, increased their efficiencies and extended their useable lifetimes. For example, due to improved manufacturing techniques and enhanced material choices, Hornsea Four is expected to have a longer operational life than previous wind farms. Development costs have also reduced as efficiencies in the build process have been captured through prior experience. This fact is also demonstrated by Lazard in Figure 10-4.

10.3.1.5 Industry-sourced data and opinion concurs with Lazard's findings, for example a CCC illustration of data from IRENA analysis (2020) showing cost reductions in and competitiveness of renewable generation technologies against fossil fuel generation [24, Figure 2.2].

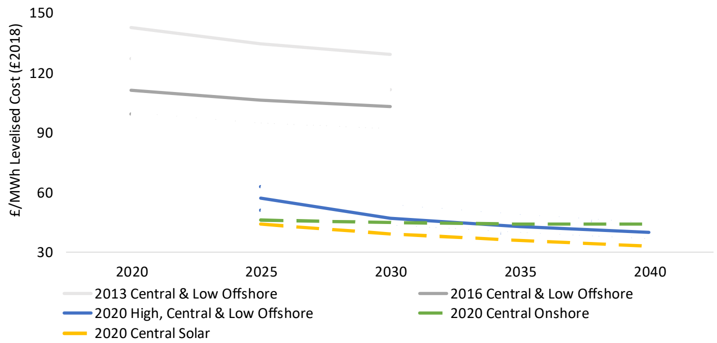
10.3.1.6 The BEIS Electricity Generation Cost report, 2020 [11] concurs with the analysis shown, and results are summarised in Figure 10-5. The analysis shows that UK-specific estimates of levelized cost of energy from offshore wind have reduced significantly since 2013; that they are predicted to fall further in the decades ahead; and that offshore wind, already being highly competitive against conventional generation costs, is closing the gap to onshore renewable developments (solar, wind).

Figure 10-4: Historical reductions in the LCOE of wind generation [10, p9]



10.3.1.7 Figure 10-5 should not however be taken as a justification for delay in development of renewable projects, in order to capture a lower future installed price. Section 5.3 explains the rationale for urgent action to develop significant capacities of low-carbon generation: time is a precious commodity. Further, it is the development of early projects which allow learnings to be implemented, technology to advance through practical application, and markets and supply chains to evolve in more efficient ways, to achieve the future cost reductions which have been forecast by BEIS and others.

Figure 10-5: BEIS Cost of Generation – Evolution of Levelized Cost forecasts [11, and Author



analysis]

10.3.1.8 The costs of offshore wind are reducing as new projects are being developed, and the technology is now becoming economically viable over a growing geography. The factors which have already pushed prices down — such as technological design, risk mitigation, efficient grid connection, efficient financing, shorter development timelines and a general commitment to tenders from governments — will continue to shape prices in emerging markets. As a consequence, the global offshore wind market is growing, and utility-scale project costs (as evidenced by an analysis of the results of the first three rounds of CfD allocation in GB, see following) are falling ahead of prior expectations.

10.4 The CfD as an indicator of GB offshore wind cost improvements

10.4.1.1 CfDs were first awarded to offshore wind projects in 2014 in the first Investment Contract round. Government has subsequently run three competitive Allocation Rounds, awarded in 2015, 2017 and 2019 respectively. CfD Allocation Round 4 (AR4), is currently scheduled to open in 2021. Details on the process required to be followed in the CfD AR4 were published in late 2021. Government had previously signalled (but not fully confirmed) their plans 'to double the capacity awarded in the last round with the aim to deploy around 12 GW of low-cost renewable generation.' Onshore wind and solar will be key building blocks of the future generation mix, along with offshore wind, to the extent that a recent budget announcement of £200m has been allocated to the AR4 offshore wind pot, and no capacity cap has been set. [18, p45 and https://www.cfdallocationround.uk/shortest-timeline]

10.4.1.2 Figure 10-6 illustrates the cumulative capacity of offshore wind contracts awarded by both allocation round and delivery year, and the weighted average strike price (all in 2012 monies) for projects within separate allocation rounds. The reduction in strike prices from round-to-round is very apparent, as is the associated increase in awarded capacity. This figure demonstrates that reductions in the cost of offshore wind as described in Section 10.3, are also being realised in GB.

10.4.1.3 The results of CfD Round 3 (issued September 2019) demonstrate the importance of offshore wind development to decarbonisation of the electricity system. Offshore wind was the major technology to be awarded a CfD in this round. Of a total 5.8 GW, 5.5 GW was awarded to offshore wind. The strike price for the allocation round was £39.65/ MWh for 2023/24 delivery and £41.61/ MWh for 2024/25 delivery, representing a significant reduction from the strike prices awarded through the CfD Round 2 in 2017[19]. This government backed subsidy scheme has contracted projects which, when delivered, will reduce wholesale electricity prices.

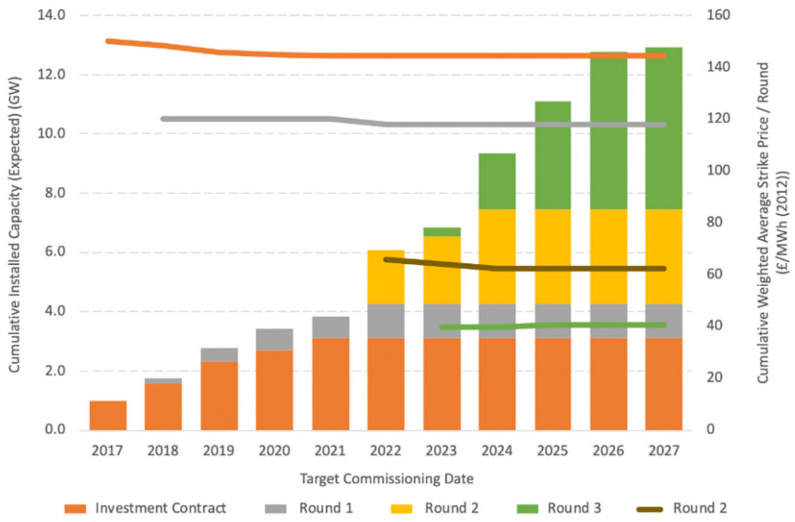
10.4.1.4 Factors which contributed to the low price outturn for offshore wind in the latest allocation round include:

- Construction risk management of this technology is well advanced in the UK due to significant experience in North Sea installations, so developer bids included less allocation to construction risk;
- The technology has evolved over the last 5 + years, making advances in MW capacity and MWh output expectations per unit of infrastructure spend over previous projects;
- The locations of the wind generators in the offshore classification are planned to be built, predominantly in wind-rich, shallow waters of Dogger Bank and other accessible areas [11, p23]; and
- Economies of scale and the development of an advanced supply chain have also contributed to the reduction in cost of offshore wind.

10.4.1.5 Many of the cost savings which have driven CfD prices lower over previous Allocation Rounds are expected to transfer through to subsequent developments, however future developments will incur their own localised construction costs which may be higher or lower than those projects which have already secured CfDs. Nevertheless, it is clear that the industry is in a strong position with regard to unit cost improvements, and is prepared to pass much of this value through to consumers via a CfD. Offshore wind in GB is currently, and is predicted to remain, super-competitive on a per MWh generated basis versus other low-carbon renewable technologies.

[19] 2023/24 versus 2021/22 delivery: 47% reduction. 2024/25 versus 2022/23 delivery: 28% reduction

Figure 10-6: Capacities of offshore wind generation awarded CfDs, and weighted average Strike Price, by allocation round and Target Commissioning Date, Author analysis from [12]



10.5 A conclusion on economic efficiency

10.5.1.1 In summary, the main points relating to the economic efficiency of offshore wind are as follows:

- Offshore wind power reduces the market price of electricity by displacing more expensive forms of generation from the cost stack. This delivers benefits for electricity consumers;
- Due to technological advances, the costs of offshore wind power are now close to grid parity in GB;
- Offshore wind power is economically attractive in GB against many other forms of conventional and renewable generation; and
- Size remains important, and maximising the generating capacity of projects improves their economic efficiency, so bringing power to market at the lowest cost possible.

10.5.1.2 The Hornsea Four development proposes a substantial infrastructure asset, capable of delivering large amounts of cheap, low-carbon electricity. Maximising the capacity of generation in the resource-rich, accessible and technically deliverable former Hornsea Zone, is to the benefit of all GB consumers, and the wind industry generally.

11 Flexibility and integration

11.1 Setting the scene on flexibility

11.1.1.1 An important enabler for the further development of the large renewable generation assets which are leading UK (and international) decarbonisation actions, are flexible technologies which optimise the integration of RES assets onto electricity grids. Significant cost and capability advancements are being made in the development of flexible technologies. New operability regimes are also successfully keeping the lights on and the power consistently flowing as RES share increases.

> *It is key that, alongside deploying renewables, the UK continues to drive innovation in the power sector to effectively build a flexible electricity system. Storage technologies, flexible demand, efficient interconnectors, and other innovations are also needed to support renewables and maintain the security of the electricity system.* [30, p6]

> *New forms of flexibility could lower future costs for consumers, by minimising expensive network reinforcement or reducing the need for additional generation, especially peaking capacity which needs to be deployed quickly to meet spikes in demand.* [18, p72]

11.1.1.2 In this chapter, we describe two important classes of integration measure which deliver flexibility and are relevant for the Hornsea Four project: electricity storage, and hydrogen.

11.2 Integration measures play a critical support role to low-carbon electricity system operability

11.2.1.1 As described previously, the utility of renewable generation assets is enhanced by the development of flexible integration measures. The technologies which provide these measures will be important to the proper functioning of high-RES electricity systems in terms of both decarbonisation and security of supply. It is anticipated that the beneficial effects of their functions on electricity system operation will increase as the proportion of renewable generation on that system also increases. Flexible integration technologies are capable of:

- Capturing 'free' energy when it is not useful and dispatching it when it has use;
- Transferring 'free' energy from where it is not useful, to a location where it is useful;
- Transforming 'free' energy from a form which is not useful, into a form which is useful; and / or
- Providing system services which help integrate renewable assets into the GB energy mix.

> *New storage technologies reduce the problem of meeting peaks in demand, and dampen wholesale price volatility, back up solar and wind intermittency, and open up the prospect of the electrification of transport.* [81, p68]

11.2.1.2 The meaning of flexible integration measures has expanded in recent years as a result of considering ways of achieving Net Zero. Not only must generation and demand assets integrate with each other within the electricity market, but also the integration of the electricity market with other energy markets is now being pursued as a way of driving down carbon emissions across many sectors.

11.2.1.3 The Energy System Catapult predict that 'Beyond bulk energy provision, a significant increase in different types of storage and flexibility is needed', concluding that major innovation and deployment of storage technologies across different timescales (from seconds to seasons) will be needed to renewable generation intermittency without the requirement for unabated fossil fuel backup systems. Their modelling suggests that day-to-day electricity system flexibility in 2050 will be provided by between 4 GW and 8 GW of electricity storage and 10 GW of interconnectors [7, pp7, 23].

11.2.1.4 NGESO's most recent FES predicts that storage will be required across hydrogen, heat, carbon and electricity to efficiently manage flexible supply and demand. Their modelling indicates the need to increase storage capacity (from 4 GW at the end of 2020) to 9 – 16 GW by 2030 and 28 – 43 GW by 2050 to balance supply and demand within the GB system [94, Table SV.22]. The NIC predicted 12 GW – 19 GW of electricity storage in 2050 in their Net-Zero power systems with 60%, 80% and 90% renewable scenarios respectively [42, pp19, 21].

11.3 Interconnection

11.3.1.1 Interconnectors (and network development) are important strategies for managing the intermittency of power generation, and localised power flows resulting from weather-dependent electricity generation. Interconnectors allow the sale of green energy to neighbouring markets when production is in surplus, and provide access to energy from other countries when demand is greater than supply. However, until the power systems in those countries become fully decarbonised, there is uncertainty around the carbon intensity of imported electricity. The FES predicts the need for 16 – 22 GW of interconnection by 2030 (up from 6 GW at the time of writing) and 20 GW – 28 GW by 2050 [94, Table SV.22]. The NIC predicted 18 GW of electricity interconnection (with other countries) in 2050 in their Net-Zero power systems with 60%, 80% and 90% renewable scenarios respectively [42, pp19, 21], a scale which was matched by the CCC in their Sixth Carbon Budget Balanced Pathways scenario [2, p136].

11.4 Hydrogen

11.4.1.1 As described in Section 7.2, the prominence of a hydrogen economy has increased in subsequent FES since the 2019 edition. This is a direct result of the requirement to meet Net-Zero, and hydrogen is an important constituent of those scenarios which meet the 2050 carbon emissions reduction target. Although the public prominence of hydrogen has recently grown, it has been forerun by a longer acknowledgement of its potential to enable deep and broad decarbonisation. As described by the Union of Concerned Scientists:

> *Hydrogen is an important energy vector which may be able to help decarbonise homes and buildings, and power road transport, however hydrogen needs to be made through large-scale industrial processes, which require significant amounts of energy. Thus, in order for hydrogen to contribute to decarbonisation, the energy source for hydrogen production must itself be low carbon.* [84]

11.4.1.2 Government's 2021 UK Hydrogen Strategy explains that hydrogen has "the potential to overcome some of the trickiest decarbonisation challenges facing our economy" [93, p2] especially in enabling the decarbonisation of industry and land transport, and as a potential substitute for current carbon-intensive marine and aviation fuels.

11.4.1.3 There are many practical ways in which a hydrogen economy can enable decarbonisation and The Industrial Decarbonisation Strategy and Transport Decarbonisation Plan (both 2021) set out the actions government is taking to bring forward hydrogen demand across industry, power, transport and heat. The major potential uses of hydrogen are:

- A further development of existing technologies such as liquefied petroleum gas (LPG) and compressed natural gas (CNG) will enable hydrogen's use in road transport, reducing the carbon intensity of freight haulage and public road transport, enabled by a national supply infrastructure;
- Hydrogen, when blended with mains gas into the National Transmission System (NTS), will reduce the carbon intensity of current gas use (industrial use, power generation, home and commercial heating and home cooking).
- A greater share of hydrogen in a blended natural gas mix will provide greater decarbonisation, leading effectively to a substitution of natural gas by hydrogen in industrial, service, commercial and domestic applications, wherever possible. An upgrade to the NTS would be required but would be cheaper than building aa new network;
- This also opens up the use of hydrogen as a power generation vector: substituting the current Combined Cycle Gas Turbine fleet (c. 300 gCO2/ kWh) and Open Cycle Gas Turbine fleet (c. 450 gCO2/ kWh) for a zero-carbon dispatchable generation technology, covering both baseload and peaking (flexibility) needs. For example, the Intermountain Power Project (Utah, USA), which is replacing 1.8 GW of coal generation with 0.8 GW of CCGT plant, capable of burning up to 30% hydrogen, 70% natural gas before 2025, and 100% hydrogen by 2045;
- Potentially only minor changes would be required to enable existing home appliances (boilers, cookers) to run on a blended fuel, especially one with only low (c. 10%) amounts of hydrogen in the blend;
- Hydrogen is a highly suitable energy vector for inter-seasonal energy storage. By using excess low-carbon electricity generation to produce hydrogen to send to storage, that hydrogen can later be released for other application when needed. Because of the low unit costs of keeping hydrogen in storage, this technology is particularly well suited to long-term use.

11.4.1.4 Methane cracking is the predominant technology in use today, however carbon is emitted as a by-product of the process. Hydrogen produced by methane cracking requires CCUS facilities to achieve Net-Zero carbon, hence the close links in government strategy and industrial plans between hydrogen production and CCUS development. Electrolysis currently accounts for only approximately 1% of global hydrogen production, however a growth in electrolysis capability and capacity opens out the prospect of using RES to produce hydrogen, in potentially significant quantities.

> *Electrolytic hydrogen … through nuclear and renewables, has the lowest carbon emissions over the full life cycle. Hydrogen can play a vital role in decarbonising sectors such as industry and heavy transport where few alternatives exist.* [85, p16]

11.4.1.5 Hydrogen produced by electrolysis, powered by low-carbon (renewable) electricity, therefore has exciting prospects for decarbonising industry; displacing petroleum products from heavy transport; replacing natural gas for heating and home use; and providing an energy vector suitable for long-term zero-carbon energy storage.

11.4.1.6 Actual examples of hydrogen produced by electrolysis from low-carbon generation (predominantly in the US) include solar-to-hydrogen at California's Stone Edge Farm Estate (where excess solar generation is used to produce green hydrogen for own-use), and California's SunLine Transit Agency, who have been operating a fleet of 16 hydrogen buses since early 2021 using green hydrogen generated from a 4 MW solar array.

11.4.1.7 In its UK Hydrogen Strategy publication, government explains that:

> *As a result of its geography, geology, infrastructure and capabilities, the UK has an important opportunity to demonstrate global leadership in low carbon hydrogen and to secure competitive advantage … When it comes to production, our 'twin track' approach capitalises on the UK's potential to produce large quantities of both electrolytic 'green' and CCUS enabled 'blue' hydrogen.* [93, p10].

11.4.1.8 Hydrogen is making tangible steps towards mainstream use in the decarbonisation of hard-to-reach subsectors of transport. In September 2020, the first hydrogen-powered UK train journey was made. In the same month, a hydrogen-powered commercial aeroplane made its maiden flight [62, 63]. NGESO estimate that annual electricity demand from road transport as a whole (incorporating both EVs and vehicles powered by hydrogen) could be between 133 and 153 TWh [94, Table CV.31], this is consistent with independent analysis carried out by SNC Lavalin (Atkins) which estimated 150 TWh [64, p12]. Both estimates are approximately 50% of current national electricity demand. The potential for use in rail, marine and air travel increase estimates of hydrogen use even further.

11.4.1.9 NGESO estimate that at between 100 and 325 TWh of electrical energy will be required annually by 2050 to produce hydrogen to meet its many potential end-uses [94, p106], the wide range is due to different Net Zero compatible scenarios producing hydrogen in different ways. The Energy System Catapult foresee the need for 'a new low carbon hydrogen economy … delivering up to 300 TWh per annum, roughly equivalent to electricity generation today' and concluding that 'Electricity generation itself may have to double, or even treble if most hydrogen is to be produced by electrolysis'. ESC also models over 600 TWh of hydrogen storage covering strategic and operational reserves to an acceptable level of security [7, pp6, 36]

11.4.1.10 The National Infrastructure Commission considered the benefits hydrogen could bring in terms of lowering the overall cost of a highly renewable electricity system in their Net zero: opportunities for the power sector publication:

> *Highly renewable systems are still a low cost option in a net zero world. The analysis once again finds that electricity system costs are broadly flat across a range of different levels of renewable penetrations. If hydrogen is deployed, providing low-carbon and flexible generation, it could further reduce the costs of highly renewable systems … The conclusions also hold in a lower demand scenario where heating has been decarbonised*

using hydrogen. [42, p7]

11.4.1.11 The hydrogen economy is set to grow in the UK with recent government announcements targeting 'Five gigawatts of "low carbon" hydrogen production capacity by 2030 – for industry, transport, power and homes – and [to] develop the first town heated by the gas by the end of the decade' [31, 93]. To support this ambition, government is providing £240M for the Net Zero Hydrogen Fund out to 2024/25 for co-investment in early hydrogen production projects, and up to £60M under the Low Carbon Hydrogen Supply 2 competition. A Hydrogen Business Model, alongside indicative Heads of Terms will be delivered in Q1 2022, which will be published alongside the promised hydrogen production strategy and "twin-track" approach which foresees a significant opportunity for the role of offshore wind in the production of green hydrogen.

11.4.1.12 The relevance of the hydrogen economy, and the potential for hydrogen to play an increasingly important role in the energy ecosystem of the future, is therefore two-fold for the development of Hornsea Four:

- The increased use of hydrogen as a low-carbon energy vector will increase the demand for electricity; and
- The integration of hydrogen production and electricity generation infrastructure will be efficient and in some cases necessary. Allowing for such flexibility at Hornsea Four within the requested planning consents will help the UK meet its Net-Zero targets.

11.5 Electricity Storage

11.5.1.1 While the Infrastructure Planning (Electricity Storage Facilities) Order 2020 removed all forms of electricity storage, other than pumped hydroelectric storage, from the definition of nationally significant energy generating stations, it is relevant to describe in this Statement of Need the important role electricity storage is required to play in the development of a low-carbon GB energy system.

11.5.1.2 Significant investment is being made in the advancement of electricity storage as an integration aid for renewables and other generation and consumption technologies. In September 2020, an International Energy Agency (IEA) European Patent Office publication, 'Innovation in batteries and electricity storage' found that battery innovation is playing a key role in the transition to clean energy technologies, and that the sector is developing rapidly:

> *Between 2005 and 2018, patenting activity in batteries and other electricity storage technologies grew at an average annual rate of 14% worldwide, four times faster than the average of all technology fields ... [and] batteries account for nearly 90% of all patenting activity in the area of electricity storage.* [86]

11.5.1.3 Other electricity storage technologies are also under development, using for example, momentum (fly-wheel), pressure (compressed air energy storage), heat or chemical processes to store energy. Many of these technologies are under development, and each has its own advantages in relation to the costs and benefits of different models of commercial operation. This Statement of Need focuses on the predominant technology: batteries. Some expert industry forecasts of future electricity storage capacity requirements have been included in Section 11.2.

11.5.2 The continuing and growing need for Balancing Services

11.5.2.1 The activities associated with integrating renewables into the GB electricity system will increase with their penetration [73, p2]. Energy balance must be managed at all times; and as renewable capacity increases, more services will be required to regain supply / demand balance when demand is either very high or very low. Further, when demand is low and renewables provide a significant share of total power generated, the maintenance of power quality and system stability levels may also require more services to achieve. Importantly, NGESO's SOF [74] describes the dynamic behaviour characteristics for a high-RES system. Plant operation may be impacted upon by these characteristics, unless integration measures are employed to limit their impact. In high-RES systems:

- Voltage and frequency may not evolve linearly in unbalanced or distributed systems and faults may evolve quickly;
- Generators may find it challenging to remain synchronous to systems following fast-evolving faults, increasing the risk of cascading faults;
- Fast-moving fault conditions will be more complicated and may not be predictable; and
- High-renewable systems will be harder to mimic for test, research or safety justification purposes.

11.5.2.2 The SOF describes two related concepts: system inertia, and system short circuit level.

System inertia and rate of change of frequency ("RoCoF")

11.5.2.3 NGESO foresee a significant decline in GB system inertia as a result of less synchronous plant connecting to the NETS, resulting primarily in the requirement for increased frequency response services. Over the coming years, the requirement for these services at certain times during the year may increase by 30 – 40% [73, Figures 1.2, 1.3]. With the expected closure or reduced running hours of many thermal plants, much system protection must be obtained in the form of synthetic inertia through frequency response services. Crucially, while system inertia is a physical property of a synchronous power plant, offshore wind plants are also able to provide inertia through synthetic means. Synthetic inertia is a clever electronic alternative to physical inertia, but it does not conform to the same rules. Synthetic inertia is provided by reprogramming power inverters attached to wind turbines so that they emulate the behaviour of synchronised spinning masses.

11.5.2.4 RoCoF is closely related to system inertia in that RoCoF increases as inertia decreases. A high RoCoF means that faults may evolve quickly, therefore response measures will need to be capable of responding quickly in order to avoid large-scale system failures. Providers of synthetic inertia, frequency response and reserve services will provide an effective countermeasure to reducing system inertia and resulting high RoCoF.

Short circuit levels and voltage dips

11.5.2.5 Short circuit level is a measure of transmission system strength, or its ability to remain within (or return to) normal operational states. Analogous to system inertia, the connection of large synchronous plants to the transmission system maintains high short circuit levels[20], and levels are expected to fall in GB as conventional capacity decreases. When this happens, critical system variables[21] may enter unstable states more easily, more frequently, and potentially for longer periods in the future [75, Figures 31, 32].

11.5.2.6 Short circuit level reductions increase the depth and geographical reach of voltage dips. Voltage dips have detrimental effects on generators and may cause disconnections of customer or generator circuits. In a system with a low short circuit level, generators at greater distances from a fault initiation location become more susceptible to those faults, implying an increase in the expectation that GB's transmission connected generating assets experience a fault in future years.

11.5.2.7 The connection, directly to the NETS, of assets that are capable of delivering voltage support services, provides the opportunity for services to be delivered to NGESO which prevent the dissipation of faults over wide geographies, thus improving the security of electricity supplies in the GB.

11.5.3 Services provided by electricity storage facilities

11.5.3.1 Critically, electricity storage is increasingly well placed to deliver a number of ancillary services for NGESO, and this is of growing importance in GB. Environmental Regulations and government policy require the closure of all GB's coal generation assets before 2025. Economic pressures, resulting from both shifts in the global gas market and changes to structural pricing in the GB electricity market are also causing the operational profiles of coal and gas assets to shift. These two points leave these traditional providers of ancillary services less available to provide, and/or less competitive in the provision of, such essential services on an ongoing basis.

11.5.3.2 Some ancillary services must be delivered at specific locations, but others are location-independent. A description of those services which remain important for the proper functioning of the electricity system, and which could be delivered by Energy Balancing Infrastructure incorporated in the Hornsea Four development, are listed in Table 11-1.

11.5.3.3 While the co-location of offshore wind generation assets with energy storage assets is not essential for either asset to make a significant contribution to the future operation of the NETS, Table 9.1 demonstrates that the co-location of those assets enables additional operational capabilities to be accessed for system benefit. Co-location is especially beneficial where connections are to the transmission, rather than to the distribution network, because the combined asset is required to meet certain system planning, notification and service obligations (see Section 9.5).

11.5.4 Growth within the electricity storage sector

11.5.4.1 A 2016 study commissioned by the former Department for Energy and Climate Change

[20] "High" short circuit levels are more resilient than "low" short circuit levels.
[21] Such as voltage or power flow.

(DECC), concluded that energy storage could result in savings of around £2.4 billion per year [from] 2030 for the UK [87, p3]. Through government and industry actions, GB is pursuing a number of projects which aim to deliver some of these benefits, although it is currently lagging behind the global leaders in battery storage.

11.5.4.2 The International Energy Agency report the year-end installed capacity of energy storage projects deployed since 2013 globally to be 5.3 GW at Grid-scale, and a further 5.4 GW 'behind the meter' [88]. The report describes that, despite a need for growth in installed capacities to return to and remain at double-digit levels in order to meet the Sustainable Development Scenario pathway[22], growth has been fragile as policy intervention has been required to support or create markets which bring investment to the sector.

11.5.4.3 This certainly holds true in the UK, where a 2015 report of energy storage assets in GB listed just 27 installed energy storage projects, with a total capacity of around 33 GWh [89, p16], a large proportion of that capacity was in the form of heritage pumped storage (hydro). A current status of the larger battery storage assets in GB demonstrates firstly that since the 2015 report, progress has been made in delivering large battery storage projects, and secondly that market participants have ambition to deliver larger projects still, because the need for more energy storage remains clear.

11.5.4.4 NGESO report that in 2020, 1.2 GW of battery storage was already in operation [94, Table ES.1], and a government report stated that a further 4 GW of storage projects was in planning [90]. In November 2020, the 'UK's largest battery' commenced commercial operation: a 50 MW / 75 MWh located in South Yorkshire, which has provided energy balancing and dynamic frequency response services to NGESO since operation [91]. Construction has started on battery storage sites of approximately double the South Yorkshire project size; and larger battery storage projects still, have already been granted planning consent.

11.5.4.5 The NGESO TEC Register shows a total of 16.5 GW of connection capacity requests from developers of either stand-alone or hybrid (storage plus solar PV) projects. These 163 projects range in proposed capacity, currently up to 500 MW [13, Accessed 9/9/2021]. A further 19 Energy Storage System projects totalling 0.6 GW and ranging from 1 MW to 50 MW are listed in the NGESO Embedded Register [92, Accessed 9/9/2021]. Further projects still are listed on the Embedded Capacity Registers [95] although some of these projects may be purely speculative with low probability of coming forward to operation.

11.5.4.6 The listing of a project on NGESO's TEC register or Embedded Register, the DNO Embedded Capacity Registers or the Planning Database, does not guarantee that the project will come forwards. A clearer indicator (although by no means providing certainty) of projects coming forwards is the Capacity Market register, which lists that 1.3 GW of Capacity Agreements have been awarded to battery storage projects since 2015. The economics of battery storage remain uncertain in GB at present, despite the clear need for further build out of the technology. It is highly likely therefore that the gap between the indicative levels of installed storage capacity required to support Net-Zero, and the combined capacity of projects which

[22] The world is not on track to meet the energy-related components of the Sustainable Development Goals (SDGs). The IEA's Sustainable Development Scenario (SDS) outlines a major transformation of the global energy system, showing how the world can change course to deliver on the three main energy-related SDGs simultaneously [https://www.iea.org/reports/world-energy-model/sustainable-development-scenario]

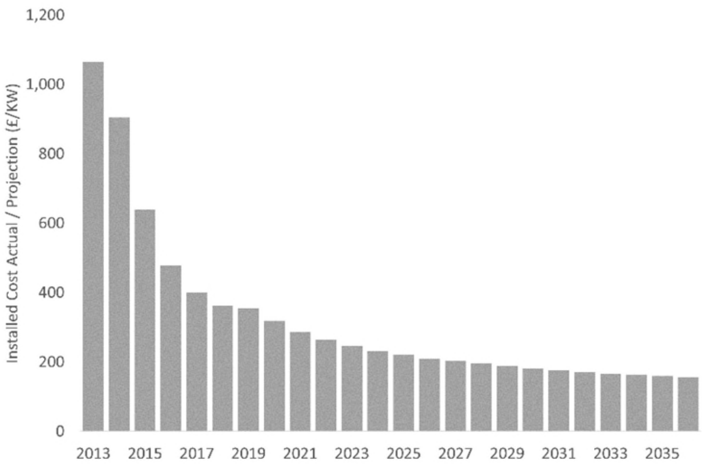
are already announced and will come forwards with some certainty, is large.

Table 11-1: The potential contributions of a storage asset at Hornsea Four to the GB electricity market, including ancillary service provision [Author analysis]

Service	Explanation	Applicability
Trading	Selling energy at market prices	The backbone of renewable generation asset investment cases. Storage reduces energy market risk as output can be directed from lower-price to higher-price periods. This helps reduce curtailment of otherwise useful low-carbon generation, and provides additional revenues to the asset.
Balancing Mechanism	Being available, on instruction, to NGESO to balance supply and demand at delivery.	Renewable generators can provide downward flexibility, but at the cost of carbon-free energy. Renewables plus storage both provide upward and downward flexibility, potentially without 'losing' any low-carbon energy. This can be dispatched over varying timeframes, from milliseconds to hours, depending on available technology.
Frequency Response	Changing output second-by-second to help maintain system frequency at the statutory level of 50 Hz.	
Reserve Operations	Changing output over minutes and hours to rebalance supply and demand following a fault or other unforeseen event on the electricity system.	
Reactive Power	Locational service which allows power to flow from source to destination.	A mandatory service for all transmission-connected assets, delivered by renewable and/or storage assets as part of their DC to AC conversion.
Inertia	A service which helps slow the rate of change of the whole electricity system in response to an unforeseen event, stopping critical faults from occurring (or if they do: escalating).	Offshore wind is able to provide inertia, and storage devices are capable of providing 'synthetic inertia' which will be important as many traditional sources of inertia – large fossil fuelled assets – close before 2025.
Black Start	A locational service which would help 'turn back on the lights' if an event caused the national electricity system to fail.	Wind alone is not capable of providing Black Start services, but standalone storage is. Co-located renewable generation plus storage may be able to provide a more robust Black Start service than would stand-alone storage.
Constraint Management	Changing output in response to local energy supply, demand and transmission issues, to ensure locational adequacy over all timescales.	Wind can provide important downward constraint management services, and wind plus storage can provide services in both directions. Because Hornsea Four connects away from the onshore connection points at the other Hornsea projects, this project will be unlikely to cause constraints in the local NETS.
Infrastructure Cost	By connecting generating assets where they are needed, less electricity transmission and distribution infrastructure needs to be built out, making national savings for electricity users.	Renewable generation and electricity storage can help with reducing new infrastructure requirements, although their benefits may be higher if co-located then if located separately.

11.5.4.7 Globally, battery energy storage systems have already achieved significant advances in technological ability and economic performance: batteries are becoming bigger, better and cheaper. Portable applications, such as consumer electronics, drove cost reduction and technological innovation in batteries in the early 2000s. Since 2010, electric mobility has been behind the growth in inventive activity in battery packs, and since then, improvements to battery packs catering for the wide range of all-electric cars and plug-in hybrid cars on the market have had positive spill over effects on stationary applications, such as grid-scale battery energy storage solutions [86, pp7, 30].

Figure 11-1: A projection of future battery component costs, [Author analysis of published data]



11.5.4.8 The Prime Minister's Ten Point Plan, announced in November 2020, includes 'nearly £500m for battery manufacture in the Midlands and north-east England' [31] to help make the vision of the UK becoming a leader in battery manufacturing capability a reality, with further cost reduction through gigascale manufacturing facilities . An industry-sourced projection of the future procurement costs of Li-Ion battery cells is included in Figure 11-1, and as cost reduction targets are met, it is highly likely that more storage projects will be commissioned.

11.5.4.9 Batteries will become well suited to displace other technologies (such as reciprocating gas engines – which are currently performing the role of meeting peak demand but for which no carbon capture solution has yet been identified) from the generation stack. In this regard the forward views of installed capacity included in Section 11.2 above are unconstrained, subject to industry achieving the cost improvements aspired to in Figure 11-1.

11.5.4.10 Additionally, it is anticipated that further ambition in the development of renewable generation assets, such as the recently announced increase to the aspiration of the offshore wind Sector Deal, now at 40 GW, would increase the important role of electricity storage within the GB electricity system. The proposal to include electricity balancing infrastructure (which could comprise of battery electricity storage) at Hornsea Four is therefore logical. The grant of a consent for such energy balancing infrastructure at Hornsea Four, would therefore allow Hornsea Four to fulfil its ambitions in providing full support to UK action plans to deliver decarbonisation.

12 In summary and in support of the case for offshore wind generation assets at Hornsea Four

12.1.1.1 This Statement of Need has shown that offshore wind generation is economically and technically viable in the UK, and that it is economically and technically preferential, for the GB electricity consumer.

12.1.1.2 The main points of this Statement of Need are as follows:

- Decarbonisation is a UK legal requirement and is of global significance. It cannot be allowed to fail, and urgent actions are required in the UK and abroad, to keep decarbonisation on track to limit global warming;
- Wind generation is an essential element of the delivery plan for the urgent decarbonisation of the GB electricity sector. This is important not only to reduce power-related emissions, but also to provide a timely next-step contribution to a future generation portfolio which is capable of supporting the decarbonisation of transport and heat sectors, through electrification;
- As part of a diverse generation mix, wind generation contributes to improve the stability of capacity utilisations among renewable generators. By being connected at the transmission system level, large-scale offshore wind generation can and will play an important role in the resilience of the GB electricity system from an adequacy and system operation perspective;
- Internationally, and importantly, GB is leading in this regard, offshore wind generation assets are becoming bigger and cheaper, each subsequent project providing a real-life demonstration that size and scale works for new offshore wind, and providing benefits to consumers in the process. Other conventional low-carbon generation (e.g. tidal, nuclear or conventional carbon with CCUS) remain important contributors to achieving the 2050 Net-Zero obligation, but their contributions in the important 2020s is likely to be low; and
- Offshore wind is already super-competitive against other forms of conventional and low-carbon generation, both in GB and more widely.

12.1.1.3 These general benefits of offshore wind generation in GB also apply specifically to the Hornsea Four project:

- The Hornsea Four development proposes a substantial infrastructure asset, capable of delivering large amounts of low-carbon electricity – enough to power in excess of 2m homes each year, from as early as the mid 2020s. This is in line with the CCC's recent identification of the need for urgent action to increase the pace of decarbonisation in the GB electricity sector;
- Hornsea Four's connection to the NETS means that it will be required to play its part in helping NGESO manage the national electricity system. This includes participating in mandatory balancing markets (to help balance supply and demand on a minute-by-minute basis and provide essential ancillary services) as well as providing visibility to the GB power market of its expected generation. This means that the low marginal cost wind power it will produce, can be forecast and priced into future contracts for power delivery by all participants, thus allowing all consumers to benefit from the market-price reducing effect of low-marginal cost offshore wind generation;
- Benefit of including permission to develop integration technology as part of the onshore infrastructure; and

- Maximising the capacity of generation in the resource-rich, accessible and technically deliverable former Hornsea Zone, is to the benefit of all GB consumers, and the wind industry generally.

12.1.1.4 In summary: Hornsea Four is capable of making meaningful and timely contributions to GB decarbonisation and security of supply, while helping lower bills for consumers throughout its operational life, thereby addressing all important aspects of existing and emerging government policy.

13 About the author

13.1.1.1 This Statement has been prepared by Si Gillett. Si has European energy sector experience, spanning 20 years of commercial, analytical and consulting roles within Utilities and the Oil & Gas sector, and provides services to UK energy market participants covering:

- Renewable generation pre-construction feasibility studies and advice for GB assets;
- GB electricity market commercial operation; and
- Electricity market transformation.

13.1.1.2 Si specialises in market change readiness and the implementation and performance of energy market regulations and in previous roles he has held responsibility for the commercial operation of electricity generation assets in GB, EU wholesale energy market trading and for the assessment and evaluation of new developments.

13.1.1.3 He prepared a Statement of Need for Cleve Hill Solar Park (DCO granted May 2020) and provided written and verbal evidence in the Issue Specific Hearings.

13.1.1.4 He also prepared a Statement of Need to support the IROPI (imperative reasons of overriding public interest) arguments made in response to the Secretary of State for Business, Energy and Industrial Strategy request for further information under Article 6(4) of the Habitats Directive and section 126(7) of the Marine and Coastal Access Act 2009 for Orsted Hornsea Project Three (DCO granted December 2020).

13.1.1.5 He holds Masters degrees in Mathematics, from Oxford University, and in Nuclear Safety, Security and Safeguards, from the University of Central Lancashire.

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