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Dogger Bank Wind Farm: An evaluation of challenges, lessons and opportunities from the UK's first HVDC offshore wind farm

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Acronyms

- CfD: Contracts for Difference
- DCO: Development Consent Order
- DESNZ: Department for Energy Security and Net Zero
- HND: Holistic Network Design
- HVAC: High Voltage Alternating Current
- HVDC: High Voltage Direct Current
- IGBT: Insulated Gate Bi-polar Transistor
- LCC: Line Commutated Converter
- NESO: National Energy Systems Operator
- OFTO: Offshore Transmission Owners
- OTNR: Offshore Transmission Network Review
- SEP: Strategic Energy Planning
- TSO: Transmission System Operator
- VSC: Voltage Source Converter

Executive summary

This report outlines the journey of developing, designing and installing the HVDC transmission system at Dogger Bank, delivered in three near identical phases known as Dogger Bank A, Dogger Bank B and Dogger Bank C. Drawing on a combination of desk-based research and interviews with project members from SSE Renewables, Equinor and Hitachi Energy, it examines the major challenges, successes and lessons learned throughout the project. The report concludes with a series of recommendations aimed at aligning policy more closely with the needs of the offshore wind industry, while also ensuring that the industry, as a whole, is primed to meet the UK's offshore wind targets of 43–50GW power by 2030.

About Dogger Bank Wind Farm

Once complete, Dogger Bank Wind Farm will be the largest offshore wind farm in the world and generate a 'world-record beating' 3.6GW of offshore wind energy—enough to power the equivalent of 6 million homes in the UK annually (Dogger Bank Wind Farm, 2023). It is also the first offshore wind farm in the UK to use a High Voltage Direct Current (HVDC) transmission system to transmit energy from the offshore farm to the onshore grid.

Dogger Bank is a joint venture between SSE Renewables (40%), Equinor (40%) and Vårgrønn (20%), with SSE Renewables leading the development and construction, Equinor leading operations and Vårgrønn providing specialist offshore wind expertise (Dogger Bank Wind Farm, 2024). Hitachi Energy is the primary contractor for the HVDC transmission system, with a total scope of supply including design, engineering, procurement, construction and installation of six converter stations. Aibel AS is the primary contractor for the three offshore platforms which house the HVDC equipment.

The HVDC system at Dogger Bank

Each phase of the Dogger Bank project operates with a symmetrical monopole ±320 kV HVDC transmission system, consisting of an unmanned, offshore HVDC converter station, two Direct Current (DC) export cables and an onshore HVDC converter station. The unmanned offshore converter station represents a significant leap in power capacity—from 900MW in previous installations to 1.2GW per station. It also features one of the industry's leanest and most compact designs.

Why opt for an HVDC transmission system?

HVDC was the chosen technology for the transmission system at Dogger Bank for several reasons. The first was related to scale and distance of the project, with all three sites located between 130-190 kilometres from shore, and the second was related to the additional benefits HVDC provides over HVAC. These include lower losses, a smaller right of way, no limits on distance and ancillary services (Rahmqvist, Monge & Sandeberg, 2023). These ancillary services, which are still being trialled and tested, include active and reactive power control, precise power flow control, protection of the grid and wind farm against transients, black-start capabilities and damping of area-wide power oscillations (ibid).

Looking forward, HVDC is also expected to play a central role in enabling more complex, integrated wind farm configurations to be developed and executed. This includes emerging and future applications such as multi-terminal and multi-infeed offshore wind farms, energy islands, Offshore Hybrid Assets, and innovative technologies like Energy Storage Systems (ESS).

Success factors and best practice

Successfully delivering Dogger Bank took many years of collaboratively developing a plan "almost from scratch" at a time when the market was less established, HVDC technology at scale in an offshore wind environment was still maturing, and flagship schemes for supporting offshore wind (e.g. the CfD and OFTO regime) did not yet exist. From the Forewind Consortium's initial planning and engagements in the early 2010s through to the current day—where only a few years are left before the project is fully operational—the team had to evolve alongside these industry changes. This included adapting to a range of regulatory, macroeconomic and local challenges, several of which have become more urgent in the time since Dogger Bank was first being developed.

Strategies and experiences from Dogger Bank provide first-hand examples of how the industry could be working today to accelerate the pace, scale and quality of offshore wind projects in the UK. The main strands of this overall successful approach include:

- Adopting a phased strategy with a standardised HVDC system design: Delivering the project in three successive phases, each with the same design, provided several benefits, including allowing the project team to leverage economies of scale and increase buying power, overlap study phases and construction efforts, and create conditions for significant improvements in quality and efficiency from one phase to the next. Copy-pasting the design also helped to minimise potential supply chain constraints by providing suppliers with a more transparent, long-term view of what would be coming down the pipeline.
- Collectively designing the innovative HVDC system: The design for the HVDC system was based on meeting a number of key requirements, including high reliability, a 1.2GW power transfer target, a lean platform concept, and compliance with the grid code. To jointly develop the detailed HVDC system design and meet these objectives, team members from SSE Renewables, Equinor and Hitachi Energy followed a 'collaborative design alignment process'. Key features of this collaboration included recognising and building on the teams' respective areas of expertise, prioritising delivering fundamental design elements and maintaining open communication throughout the duration of the project.
- Focusing on early risk mitigation and minimising interventions: Early risk mitigation was a key focus in the design process for Dogger Bank's HVDC system. Given the scale and novelty of the project, extensive preparation went into the initial planning process, with the team prioritising a "safe by design" approach to ensure risks were addressed proactively.
- Developing and maintaining a collaborative working culture: The success of Dogger Bank was also attributed to the strength of the working relationships between SSE Renewables, Equinor and Hitachi Energy. Made up of stakeholders from all three parties, the Dogger Bank team acted as one team and promoted a culture of transparent and respectful communication which helped them rapidly resolve and adapt to challenges. Other factors which contributed to maintaining a collaborative spirit throughout the many years of working together included sharing a sense of ownership over the project, building on pre-existing relationships and actively creating a cooperative working culture.

Applied from the early days of the project, these key strategies created a solid foundation for addressing challenges as and when they arose, such as planning challenges, macroeconomic challenges and local, onsite challenges.

- Project planning challenges: The project team had to navigate lengthy permitting and planning processes, with the Development Consent Order (DCO) taking nearly four years to secure. This delay was partly due to the nascent state of the offshore wind industry at the time but also the resource- and time-consuming consenting process for Nationally Significant Infrastructure Projects (NSIPs).
- Macroeconomic and geopolitical challenges: The project team faced several macroeconomic and geopolitical challenges related to the COVID-19 pandemic, the war in Ukraine and the global energy transition—which has created a supply chain 'squeeze' for HVDC components.
- Local and onsite challenges: The project team faced several local and onsite execution challenges related to distance, unique weather conditions, vessel procurement, labour and skills, and coordination with third-party developers. For example, the distance of up to 196 kilometres between the shore and offshore sites increased the cost and risk of errors, while also making communication with teams at sea, who were sent off for two weeks at a time, more complex.

Policy recommendations

Based on challenges and successful practice from Dogger Bank's transmission journey, this report presents a series of policy recommendations for supporting sustainable, accelerated growth of offshore wind projects in the UK.

Recommendations for policymakers

- Introduce a maximum permitting time for offshore wind projects: The government should consider ways to streamline permitting and DCO timeframes, for instance by simplifying requirements, particularly for locations with lower environmental risks, and by introducing a maximum permitting time for offshore wind projects. The Global Wind Energy Council proposes mandating a maximum time of three years (with additional time allowed under extraordinary circumstances) and granting deemed consent if permitting authorities fail to meet the agreed timeframe (GWEC, 2024).
- Involve statutory consultees earlier in the project approval process: Earlier involvement from statutory consultees would give developers more foresight in the permitting process, allowing them to streamline the application process by addressing potential roadblocks and risks ahead of time.
- Increase domestic investment in R&D related to HVDC: To leverage the expertise and skills the UK is building up in HVDC, the government should consider boosting investment in R&D for HVDC technology, particularly where this concerns potential ancillary services and technologies with potential synergies, such as ESS. The HVDC Centre suggests channelling investment towards universities and doctoral centres, to develop early designs, carry out factory testing and conduct grid-scale trials of HVDC ancillary service control schemes (National HVDC Centre, 2021a).
- Increase grid capacity to support integration of offshore renewable energy sources: To prevent grid infrastructure from becoming a bottleneck, the government should continue its work developing a proactive network planning framework. Recommended measures include carrying out regular

assessments of transmission network capacity needed to support offshore wind projects, installing grid upgrades in tandem with offshore developments, ensuring that regulatory risk assessments enable anticipatory investments, and considering compatibilities with emerging technologies such as energy storage (Pfeifenberger et al., 2024). This recommendation aligns with the objectives of the Strategic Energy Planning (SEP) process being developed by NESO, which should be fully and robustly delivered to ensure timely, coordinated grid infrastructure that supports delivery of offshore wind targets. Increasing grid capacity in a systematic, integrated way could also help to reduce costs and development timelines, as well as increase grid resilience.

- Support growth and stability of domestic HVDC supply chains through standardisation: To address HVDC supply chain constraints, accelerate the pace at which components are produced and increase interoperability, the government should support the development of standardised functional designs for UK offshore HVDC systems. For instance, it could seek alignment with the European market in taking a programmatic approach to HVDC offshore network delivery similar to that adopted by TenneT.

Recommendations for the offshore wind industry

- Standardise HVDC system designs across multiple projects: Developers should look to transition away from optimising individual projects and towards standardising designs across multiple projects or phases. Dogger Bank exemplified the benefits of using a scalable, “copy paste” approach, including cost savings, rapid improvements in efficiency and increased resilience against macroeconomic and onsite challenges.
- Develop standardised grid integration study methods: To effectively mitigate the risk of negative grid interactions and shorten study timelines and costs, NESO and developers should collaborate to reach consensus on a standardised method for conducting grid interaction studies, as well as develop a set of harmonised success criteria that ensures consistency and reliability across different projects. For this to be most effective, a safe data-sharing process would need to be developed through collaboration between developers, OEMs and TSOs, e.g. in order to share models which accurately represent real system dynamics.
- Adopt a ‘collaborative design alignment process’ with suppliers and other involved parties: During development phases of an offshore wind farm, a collaborative design alignment process—founded on open, transparent communication, respect for each party’s different areas of expertise, and a focus on delivering fundamental design features—helps to drive forward the design process and study phases in a more coordinated, focused way.
- Prioritise long-term, collaborative business partnerships: Entering into longer-term business partnerships can provide mutual benefits for suppliers and developers. For suppliers, long-term contracting provides visibility and foresight into procurement needs years ahead of time, and for developers, it reduces the likelihood of delays procuring necessary components and equipment. Factors that enabled the Dogger Bank team to successfully maintain a collaborative partnership over many years include signing a preferred supplier agreement, contracting across multiple project phases, sharing leadership responsibilities, and operating as one team when addressing development, design, and execution challenges.

- Increase information and knowledge sharing between third parties, e.g. developers working separately on the same zones or sites: The competitive nature of the offshore wind sector can inhibit collaboration between developers. Where relevant, developers should look for opportunities to share research, coordinate onshore/offshore transmission construction activities and even jointly carry out local community engagement activities. Experiences from Dogger Bank highlight that it is both productive and possible for competing developers to cooperate without forgoing the advantages of competition.

Introduction and report scope

Once complete, Dogger Bank Wind Farm will be the largest offshore wind farm in the world. It is also the first offshore wind farm in the UK to use a High Voltage Direct Current (HVDC) transmission system to transmit energy from the farm to the grid.

This report outlines the journey of developing, designing and installing the HVDC transmission system at Dogger Bank, delivered in three near identical phases known as Dogger Bank A, Dogger Bank B and Dogger Bank C. Drawing on a combination of desk-based research and interviews[1] with project members from SSE Renewables, Equinor and Hitachi Energy, it examines the major challenges, successes and lessons learned throughout the project. The focus is on the development and execution strategy for the HVDC transmission system, which included the decision to (1) adopt a three-phase delivery approach with standardised components, (2) collectively design the innovative HVDC system, (3) focus on early-stage risk mitigation, and (4) develop and maintain a collaborative working culture.

The report explores how these strategies helped the Dogger Bank team overcome various macroeconomic and onsite challenges, some of which, in light of the global energy transition and supply chain 'squeeze' for offshore wind components, have since become more pressing. The report also broadly examines the role of HVDC technology in the UK's Net-Zero transition, exploring how lessons from Dogger Bank could be shared to guide the development of future projects. It concludes with a series of recommendations aimed at aligning policy more closely with the needs of the offshore wind industry, while also ensuring that the industry, as a whole, is primed to meet the UK's offshore wind targets of 43–50GW power by 2030.

Section overview

- Section 1 presents the Dogger Bank Wind Farm project. This includes a geographical snapshot of Dogger Bank's three sites, a summary of project developments and progress to date, and an overview of the partnership between SSE Renewables, Equinor, Vårgrønn and Hitachi Energy.
- Section 2 provides an overview of High Voltage Direct Current technology (HVDC) and explains why this was the chosen technology for Dogger Bank's transmission system. This includes a comparison of HVDC and High Voltage Alternating Current (HVAC), a summary of its grid-supporting services, and a discussion of its application in future offshore wind configurations such as multi-terminal and multi-infeed offshore wind farms.
- Section 3 outlines the factors which have played a central role in the successful, timely delivery of Dogger Bank to date. These success factors focus on the benefits of collaboration, standardisation and early-stage risk mitigation in developing and delivering the UK's first offshore wind farm with an HVDC system.
- Section 4 describes the challenges and risks the project team faced throughout the development and execution of Dogger Bank. These are divided into planning-related challenges, macroeconomic challenges and onsite challenges. Illustrative examples of how the Dogger Bank team mitigated and adapted to these challenges are also included.

[1] Interviewees are referred to throughout using their initials – for a full list of interviewees names, see Box 1 in the Annex.

- Section 5 reflects on Dogger Bank's transmission journey, situating challenges and successes within the context of the current offshore wind industry. This section considers how these experiences relate to broader discussions about the UK's energy transition and proposes opportunities for promoting more long-term collaborative partnerships and increased adoption of HVDC technology, as well as developing more resilient networks and HVDC supply chains in the UK.
- Section 6 presents a range of policy recommendations for supporting rapid, sustainable growth of the UK's offshore wind industry. Based on best-practice from Dogger Bank, this includes recommendations for policymakers, as well as recommendations for stakeholders in the offshore wind industry supply chain.

Section 1: Dogger Bank Wind Farm – an overview

This section introduces the Dogger Bank project, providing information about the project in terms of its geographical location, developments and progress to date, and the partnership between SSE Renewables, Equinor, Vårgrønn and Hitachi Energy.

1.1 About Dogger Bank – site, partnership, timeline

Dogger Bank Wind Farm is an offshore wind farm delivered in three phases: Dogger Bank A, Dogger Bank B and Dogger Bank C. These three sites are each situated between 130 and 190 kilometres from the coast of the Northeast of England.

Fig 1: Image of Dogger Bank A, B and C wind farm sites

Image source: Dogger Bank Wind Farm

Once complete, Dogger Bank Wind Farm will be the largest offshore wind farm in the world and generate a 'world-record beating' 3.6GW of offshore wind energy—enough to power the equivalent of 6 million homes in the UK annually (Dogger Bank Wind Farm, 2023). It also features the leanest, most power-dense HVDC system design for an offshore wind farm, a central component of which is the world's first unmanned, offshore converter platform.

The development is a joint venture between SSE Renewables (40%), Equinor (40%) and Vårgrønn (20%). SSE Renewables leads the development and construction, Equinor leads operations and Vårgrønn provides specialist offshore wind expertise. Hitachi Energy is the primary contractor for the HVDC converter system, with a total scope of supply including design, engineering, procurement, construction and installation of six converter stations. Aibel, with whom Hitachi Energy has a strategic partnership, is the primary contractor for the three offshore platforms which house the HVDC equipment. See Box 1 for a summary of each partner and their respective roles.

Box 1: The partners

SSE Renewables is a leading developer and operator of renewable energy generation, focusing on onshore and offshore wind, hydro, solar and battery storage. Part of energy infrastructure company SSE plc, UK-listed in the FTSE100, it is delivering clean power assets to increase SSE's operational renewable generation capacity from 5GW today to up to 9GW by 2027 as part of a £20bn clean energy plan, the five-year Net-Zero Acceleration Programme (NZAP) Plus. This includes delivery of the Dogger Bank Wind Farm.

Equinor is the UK's leading energy provider, supplying electricity, natural gas and oil, and aims to reach net zero emissions globally by 2050. A broad energy company, Equinor has been operating in the UK for nearly 40 years. Equinor supports the UK economy by investing billions in energy infrastructure, working with over 700 suppliers across the country. Equinor has plans to reach an installed net capacity of 12-16GW of renewable energy by 2030, with two-thirds of this capacity coming from offshore wind.

Vårgrønn is a Norway-based offshore wind company powering the energy transition through development, construction, operation and ownership of renewable energy generation and green infrastructure. Vårgrønn is a joint venture between the energy company Plenitude (Eni) and the Norwegian energy entrepreneur and investor HitecVision.

Hitachi Energy is a global technology leader serving customers in the utility, industry and infrastructure sectors with innovative solutions and services across the value chain. Hitachi Energy have installed more than half of all HVDC VSC links in the world. They employ around 45,000 people in 60 countries and generate business volumes of over $13 billion.

Aibel is a leading provider of EPCI services (Engineering, Procurement, Construction and Installation) who designs, builds and maintains platforms and other critical infrastructure for the energy industry. The company is one of the largest suppliers of innovative and sustainable solutions on the Norwegian continental shelf.

1.2 A brief history of the project to date

The delivery of Dogger Bank Wind Farm in three phases reflects how the seabed was originally leased as a cluster of locations within the Dogger Bank Zone. A brief timeline of the development from the initial planning period until now is summarised in Box 2.

In 2010, the Forewind Consortium—a consortium between SSE, Equinor, Statkraft and Innogy—began the planning, assessment and engagement process to request planning consent for four locations within the Dogger Bank Zone. These four locations were initially known as Teesside A, Teesside B, Creyke Beck A and Creyke Beck B. Six months into this process, the Forewind Consortium's development team had already entered into discussion with Hitachi Energy to explore how HVDC technology could be used to connect the wind farm zone to the UK network.

In 2015, all four locations received planning consent from the UK government, and in 2017 new ownership arrangements were confirmed, with SSE and Equinor moving forward with Creyke Beck A, Creyke Beck B and Teesside A under the new name of Dogger Bank Wind Farm. Creyke Beck A and B, along with Teesside A, were respectively renamed Dogger Bank A, B and C. In 2019, all three sites were successful in the government's Contract for Difference (CfD) auction and construction work began on Dogger Bank A shortly thereafter. In 2022, Vårgrønn acquired a 20% stake in Dogger Bank Wind Farm from Plenitude.

To date, significant progress has been made on the project. In line with originally scheduled plans, Dogger Bank A achieved first power in October 2023 and is on track to be complete in the second half of 2025. Dogger Bank B will begin producing power in 2025, with commercial operations starting in 2026, and Dogger Bank C is anticipated to enter full service by 2027 (SSE Renewables, n.d.). SSE Renewables and Equinor are also exploring the possibility of expanding the project with an additional phase, Dogger Bank D, which could increase the wind farm's capacity by up to 1.32 GW.

Box 2: Timeline of the project to date

- 2010: Forewind Consortium begins process to apply for planning consent in four areas within the Dogger Bank Zone
- 2015: All four project areas receive planning consent from UK government
- 2017: New ownership arrangements confirmed, with SSE and Equinor moving forward with Creyke Beck A, Creyke Beck B and Teesside A under the name Dogger Bank Wind Farm
- 2019: All three phases of the project are successful in the UK government's 2019 Contract for Difference (CfD) auction
- 2019: Construction work begins on Dogger Bank A and B
- 2022: Vårgrønn acquires a 20% stake in Dogger Bank Wind Farm from Plenitude
- 2023: First unmanned HVDC converter station is installed at Dogger Bank A
- 2023: First power is introduced at Dogger Bank A
- 2024: Unmanned HVDC converter station is installed at Dogger Bank B
- 2024: Foundation installation campaign begins on Dogger Bank B
- 2024: Inter-array cable works are completed on Dogger Bank A

Section 2: HVDC Technology

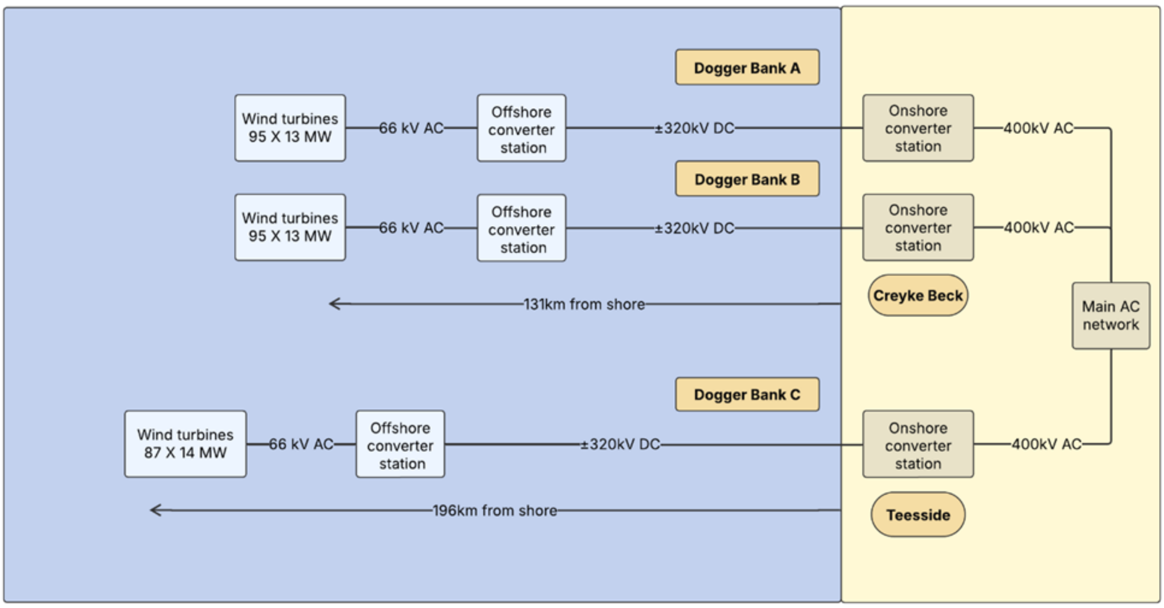
This section provides an overview of HVDC technology and explains why this was the chosen technology for Dogger Bank's transmission system. It describes the specific HVDC system installed at Dogger Bank, discusses the advantages of HVDC compared with HVAC, with a focus on grid-supporting services, and provides an overview of two primary types of HVDC converters, LCC and VSC. It also explores emerging and future applications for HVDC offshore wind farms, including interconnected configurations and related technologies, such as Energy Storage Systems (ESS).

2.1 The HVDC transmission system at Dogger Bank

Until recently, offshore wind farms in the UK had exclusively relied on High Voltage Alternating Current (HVAC) transmission systems to transmit power to the terrestrial grid (National HVDC Centre, 2023). This approach involves using HVAC cables for point-to-point connections to the grid—a suitable choice when an offshore wind farm is located close to shore, typically at a distance of less than 50km (Jansen et al., 2022). However, given the UK's ambitious renewable energy targets and the subsequent uptick in offshore wind projects, developers are looking to build further and further away from the coast. This is why offshore wind farms using High Voltage Direct Current (HVDC) systems—where the power is converted to direct current (DC) before transmission to shore—are gaining momentum. Dogger Bank Wind Farm represents the first application of this HVDC technology for an offshore wind farm in the UK, setting a precedent for other HVDC projects in the pipeline.

Dogger Bank A, B and C operate with a symmetrical monopole HVDC transmission system, consisting of an unmanned, offshore HVDC converter station, two Direct Current (DC) export cables—one with a positive pole and one with a negative pole[2]—and an onshore HVDC converter station. See fig 2. for an illustration of the transmission system.

Fig 2: Illustration of the HVDC transmission system at Dogger Bank



[2] In a symmetrical monopole configuration there are two poles, one with a positive voltage polarity (e.g. +320 kV) and the other with negative voltage polarity (e.g. -320 kV). The amount of current in each pole is equal but flows in an opposite direction.

Each Dogger Bank project phase operates with a ±320 kV HVDC transmission system. Voltage transformers on the offshore platform step up the voltage from the turbine arrays from 66 kV to 400 kV. The offshore converter then converts this 400 kV AC into ±320 kV DC, which is then transmitted through DC cables to the shore. Once the DC power reaches the onshore converter station, it is converted back from ±320 kV DC to 400 kV AC by the onshore converter. The final part of the transmission system is a short high-voltage AC circuit, which spans roughly two kilometres, connecting the onshore converter station to the national electricity transmission system. This entire final process operates at 400 kV.

The HVDC transmission system at Dogger Bank features an unmanned, offshore converter platform which represents a significant leap in power capacity. At 1.2GW per platform, it boasts one of the leanest and most powerful designs available. In total, the team achieved a 70% reduction in the weight of the topside—creating a design which is more power dense, has lower losses, and has a smaller environmental footprint than previous designs at 900MW.

Fig 3. The lean, unmanned offshore converter platform

Image source: Dogger Bank Wind Farm

2.2 Why opt for HVDC?

There is a project-specific 'breakeven distance' at which HVDC becomes the more cost-effective option for an offshore wind farm, due to the fact that while HVDC systems have lower line losses and use cheaper cables compared with HVAC, they also require expensive onshore and offshore converter stations (Jansen et al., 2022). A typical figure for a breakeven distance would be between 70 and 90 kilometres (Jansen et al., 2022; Warnock et al., 2019). Dogger Bank A and B are located 131 kilometres from shore, and Dogger Bank C is 196 kilometres from shore, making HVDC the optimal choice, as far as distance was concerned, for the transmission system.

HVDC also offers several advantages over HVAC for windfarms located far offshore:

- Lower losses: HVDC systems experience fewer power losses over extended distances, due to a DC cable's lack of reactive charging current (Kamwa, 2024; Koondhar et al., 2023)
- Smaller 'right of way' for the cables: HVDC is an energy-dense technology which, compared with HVAC, requires less cables to transmit the same amount of power.
- No distance limitations: While there is a maximum length that cables in an HVAC system can go to without requiring compensatory equipment, HVDC has no limits (although losses will grow in proportion to the distance).
- Grid support and ancillary services: HVDC systems have the added advantage of supporting the grid by providing ancillary services. This is linked to the fact that, with an HVDC transmission system, power flow is fully controllable, which allows renewable energy to be more efficiently integrated into the grid.

2.3 Types of HVDC converters in an offshore HVDC wind farm – VSC and LCC

The high voltage system for Dogger Bank is based on a type of converter called a Voltage Source Converter (VSC). The other main converter technology applied to HVDC projects is a Line Commutated Converter (LCC). The differences between these two types of converters are outlined below, as well as the specific advantages of VSC for HVDC offshore wind farms.

LCC, the more mature technology, is primarily based on power electronic thyristors, which are semiconductor devices that are switched on through an external control signal. Once triggered into conduction by a small current or voltage, a thyristor remains on until the current flowing through it is reduced below a certain threshold. It switches off through a process called commutation, in which the current is transferred from one thyristor to another (National HVDC Centre, 2023). LCC relies on the AC line voltage for commutation, meaning that the switching operation is directly tied to the characteristics of the AC voltage grid.

By contrast, VSC technology, which was originally developed by Hitachi Energy in the mid-1990s, uses Insulated Gate Bi-polar Transistors (IGBTs) that can be switched on and off to control action independently of the AC system (National HVDC Centre, 2023). This makes VSC HVDC particularly valuable in terms of its flexibility and grid-supporting potential (Kamwa, 2024; Jain, Sakamuri & Cutululis, 2020; Koondhar et al., 2023; Korompili, Wu & Zhao, 2016). It has always been the preferred choice for connecting offshore wind farms because it does not require a strong voltage source or large AC filters and because of the limitations associated with LCC requiring a strong AC grid at both ends for commutation (Koondhar et al., 2023). Its smaller overall footprint also makes it suitable for offshore application, where costs increase in relation to the amount of space occupied. PS and ER highlighted ways that VSC is considered to provide additional functionality over LCC technology:

> "One of the benefits of the VSC technology is the controllability [...] So in a VSC HVDC system, you can basically fully control the power flow that you have on the link as well. We also have a very low losses, especially when it comes to longer distances."

The HVDC system at Dogger Bank uses Hitachi Energy's fifth generation VSC HVDC technology, HVDC Light, which has some of the lowest losses in the industry (Hitachi Energy, n.d.). It represents the second ever application globally and first application for an offshore wind farm. PS and ER of Hitachi Energy spoke about how the initial R&D process for Hitachi Energy's VSC HVDC technology had been focused on making a more compact design with lower power losses:

> "[There was] a lot of focus in the beginning to get the losses down to a decent level. Now we are on par with the other technology."

Box 3: VSC and LCC additional terms and definitions

- Electronic thyristors: a type of semiconductor device used in LCC for controlling and switching electrical power. Electronic thyristors act as controlled switches that, once triggered by a small current or voltage, allow current to flow in one direction and remain conducting until the current is reduced below a certain threshold.
- Insulated Gate Bipolar Transistors (IGBT): a type of semiconductor device used in VSC to control the flow of electrical power. They enable rapid switching of large power levels, improving the reliability and performance of power-intensive systems such as power converters and renewable energy technologies (HVDC Centre, 2023). IGBTs are switched on and off at frequencies determined by Pulse-Width Modulation (PWM) algorithms, allowing the creation of any desired voltage waveform (Korompili, Wu & Zhao, 2016).
- AC filters: electrical components used to reduce or eliminate unwanted noise, harmonics or fluctuations from AC systems. These filters smooth the waveform of the AC power, ensuring that the electrical output is stable and within the desired frequency range.

2.4 VSC grid-supporting services

Large-scale integration of renewable energy into the power system will introduce more variable power flows, in turn making it more challenging to maintain the stability and reliability of the grid (Boeck et al., 2016). To this end, VSC HVDC offers a range of ancillary services which can help to increase grid flexibility and stability. Rahmqvist, Monge and Sandeberg outline the following advantages of VSC HVDC systems for grid support: flexible control of active and reactive power for voltage and frequency regulation, increased reliability and security of power supply, ancillary services, damping of wide-area power oscillations, black start capabilities, AC grid restoration, and improved power flow control to optimise the operation of the AC grid near its thermal limits (Rahmqvist, Monge & Sandeberg, 2023). These ancillary services are summarised below.

2.4.1 Control of active and reactive power

In a VSC HVDC system, active and reactive power are independently controlled using power electronics that switch between isolating and conducting modes, improving grid stability (Rahmqvist, Monge & Sandeberg, 2023). VSC HVDC systems provide precise control over power flows, allowing the power to flow in both directions and providing ‘superior voltage and frequency management’ (Kamwa, 2024; Koondhar et al., 2023). The control system is also extremely rapid, allowing for direction changes in milliseconds. This benefits the grid by allowing more power to flow via transmission infrastructure such as overhead cables.

2.4.2 Black-start capabilities and AC grid restoration

VSC HVDC systems offer several advantages when it comes to black-start and AC grid restoration after a blackout (Korompili, Wu & Zhao, 2016; Rahmqvist, Monge & Sandeberg, 2023; Jain, Sakamuri & Cutululis, 2020). Firstly, since the voltage in a VSC HVDC system is highly responsive, it can prevent dips or over-voltages (Korompili, Wu & Zhao, 2016). Additionally, the active and reactive power control allows the VSC HVDC to regulate the frequency of the AC grid and maintain it within acceptable limits. For example, a restoration test of the NEMO link between the UK and Belgium demonstrated how the VSC HVDC interconnector successfully energised a ‘dead’ Belgian grid from the UK side (Jain, Sakamuri & Cutululis, 2020).

2.4.3 AC grid decoupling

Fast, precise control of active and reactive power also improves the dynamic performance of the system during disturbances such as transients[3] and voltage flickers. Since the converters in the VSC HVDC system decouple the grid side from the wind farm side, disturbances from the AC grid are isolated and therefore not transferred between the two sides. Likewise, transients caused by energising the wind farm do not affect the grid. As a result, power quality is improved on both sides. (Korompili, Wu & Zhao, 2016). PS and ER provided an example of how VSC helps to mitigate the impact of transients in the grid:

> “If an electrical transient were to propagate to the offshore side, it would create mechanical forces on the wind turbines, which is not something we want to see [...] DC, as opposed to AC, makes the offshore wind farm immune to these types of transients—so that’s also a significant advantage.”

2.4.4 Managing wide-area oscillations

Due to the fast active and reactive power control, VSC HVDC can also provide effective damping for mitigating electromechanical oscillations, which are fluctuations in the power system caused by disturbances such as faults or sudden changes in load (Korompili, Wu & Zhao, 2016).

2.5 Emerging and future offshore applications of HVDC transmission technology

Growing demand for renewable energy is driving the development of more advanced applications of HVDC for offshore wind farms. Examples of emerging applications of HVDC in this area include multi-infeed and multi-terminal offshore wind farms, energy islands, Offshore Hybrid Assets (OHA) and co-location of energy storage systems (ESS). These integrated models could help to improve grid resilience, stability and security, whilst also reducing costs and optimising use of space and resources. These are discussed in more detail below.

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[3] Transients in the onshore grid are common and typically occur due to events like trees falling on overhead power lines. These transients cause a brief voltage dip, which is usually experienced as a small “blink”.

2.5.1 Multi-terminal/multi-purpose interconnection offshore wind farms

Developers tend to design projects with radial interconnections to shore, meaning that power generated by the wind farm is transmitted to a single location on the grid. Multi-purpose interconnected offshore wind farms provide an alternative means of bringing power to shore by enabling flow from the onshore grid to an offshore facility for re-injection at another onshore site. As PS & ER explained:

> "The idea is that you have two onshore stations and an offshore station, so you can combine trading on that link and then also transmit power from the offshore wind."

For example, a multi-purpose interconnected offshore wind farm could be connected to its nearest site in Scotland while transmitting power directly to locations with higher demand, e.g. London, thereby bypassing the onshore grid to deliver power straight to consumers. National Grid ESO found that including the use of multi-purpose interconnectors could reduce consumer costs by £3–6 billion (Felder et al., 2022). It could also reduce the number of onshore landing points by up to 50% (ibid).

These multi-purpose projects would require standardised HVDC system components—including standardised converter stations and substation equipment—for all interconnection terminals (Silverman & Glatz, 2024). On this front, the UK has developed its first HVDC multi-terminal project, the Caithness Moray HVDC Link, which includes three 320 kV terminals built by Hitachi Energy and connects the Viking onshore wind farm on the Shetland Islands to the Scottish mainland (ibid). See fig 4. for a view of the onshore converter station.

2.5.2 Multi-infeed offshore wind farms

A multi-infeed system refers to the integration of multiple offshore wind farms, via HVDC connection, to a single onshore network. The HVDC Centre suggests that integrated solutions like multi-infeed systems require half the amount of transmission infrastructure, helping to reduce pressure on the HVDC supply chain, whilst also having a smaller impact on onshore sites (HVDC Centre, 2023).

2.5.3 Co-location of energy storage systems

Increasing the flow of renewable energy sources into the grid will require an increase in technologies providing stability and flexibility support. In response to this, HVDC offshore wind farms have been identified as prime areas for co-locating energy storage systems (ESS).

There are many different types of ESS technologies which could be co-located within the infrastructure of an HVDC offshore wind farm to provide ancillary services and store excess energy generated during periods of high wind and low demand. Battery energy storage systems (BESS), a form of electrochemical energy storage already readily available, are promising in this regard. BESS could help to manage the short-term intermittency and variability effects which accompany increased integration of renewable energy (Attya, Dominguez-Garcia & Anaya-Lara, 2018; Antony & Shaw, 2016). This type of ESS is also expected to be the most cost-effective option for adding more renewable energy generation to the mix (Rabanal et al., 2024)

Whilst there are still economic barriers in place due to the novelty of ESS technology, the technical viability is growing. Currently, Dogger Bank D is being considered as a potential site for ESS, which could involve multiple buildings and containers at the selected converter station site (SSE & Equinor, 2024).

2.5.4 Offshore Hybrid Assets (OHA)

With projects being located both further from the shore and at the crossroads of different countries (as in the case of all projects in the Dogger Bank Zone) different types of HVDC connections linking one farm to multiple countries are being developed. These projects, called Offshore Hybrid Assets (OHAs), allow clusters of farms and interconnectors to share, via an offshore converter station, a single connection point (SSE & Equinor, 2024). By connecting national markets with each other, OHAs can have several benefits for the integration of offshore wind power across regions—including allowing electricity to flow into transmission systems of different countries based on levels of demand, enhancing grid flexibility and reducing environmental impacts. The Dogger Bank team is working alongside National Grid to explore the possibility of delivering Dogger Bank D as an OHA (SSE & Equinor, 2024).

2.5.5 Energy islands

One type of OHA is an energy island, which involves linking wind farms to an artificial island interconnecting several different countries. The first of these are already in planning. One significant example is the North Sea Wind Power Hub, spearheaded by TenneT, which would be located in the Dogger Bank Zone and act as an interconnector between six different countries. The development process would involve constructing the island as a hub for electrical infrastructure to interconnect United Kingdom, Netherlands, Germany, Norway, Denmark, and Belgium (Jansen et al., 2022). Power would be transmitted from the windfarms via HVAC, then converted to HVDC at the island, and then transmitted to the six countries. This would ensure that no energy would be wasted, and that in the case of a transmission failure, energy could be diverted to another country (Warnock et al., 2019). As with multi-infeed and multi-terminal solutions, this could also produce cost savings from reduced infrastructure requirements.

Fig 4. Onshore station for Caithness Moray multi-terminal HVDC link

Image source: TODD Architects

Section 3: Success factors and best practice

This section of the report provides an overview of factors which played a key role in the successful, timely delivery of Dogger Bank phases A, B and C. These examples of best practice were identified during interviews with members of the project team, including stakeholders from SSE Renewables, Equinor and Hitachi Energy, and primarily focus on the advantages of standardisation, collaboration, and risk mitigation in delivering the UK's first offshore wind HVDC system.

These success factors include:

(1) Adopting a three-phase strategy with a standardised HVDC design
(2) Collectively designing the innovative HVDC system
(3) Focusing on early risk mitigation and minimising interventions
(4) Developing and maintaining a collaborative working culture

3.1 Adopting a three-phase strategy with a standardised HVDC design

Dogger Bank Wind Farm has been delivered in three stages—A, B, and C—with each phase receiving the same HVDC system components. With Dogger Bank C nearing the end of construction, the result of this approach is a portfolio of three near identical projects which have been constructed in quick succession.

Why three phases?

The three-phase approach was a key part of the project development and execution strategy for Dogger Bank. Specifically, delivering three separate projects "as one project" allowed the team to focus on developing a standardised HVDC system design which could be effectively repeated across all phases. This added significant value to the project in terms of cost and time savings. As AB of SSE explained:

> "The biggest advantage of the three phases is that we could build as one project. We could deliver economies of scale, in terms of our buying power in the market. The other advantage was learning lessons from one phase to the other and seeing consistent improvements."

Why a standardised HVDC design?

Standardisation in an offshore wind context refers to the development of consistent, repeatable designs for components, such as turbine foundations and cables, and, in this case, transmission components. Research suggests that standardising designs will be key to accelerating the rate of build for offshore wind farms (GWEC, 2024; Andrey et al., 2022; 2021; Mangat et al., 2022; Silverman & Glatz, 2024). The Global Wind Energy Council state, for instance, that standardising technology design and functional requirements is 'essential for the successful delivery of a coordinated offshore grid' (GWEC, 2024).

Standardisation can help to streamline production, reduce costs of installation and system integration, increase quality and consistency of components and enable economies of scale across projects. It can also ease supply chain bottlenecks and constraints by allowing manufacturers to focus on a single equipment standard, as well as increase compatibility with future markets (Andrey et al., 2022). More generally, standardisation also increases predictability and reduces risks involved in the design and installation process (Finocchi, 2021).

With a project the scale of Dogger Bank, standardising the HVDC design and rolling it out in three phases provided the project team several of these advantages, with the following specifically highlighted during interviews:

1. Increasing buying power in the market
2. Overlapping study and construction phases across projects
3. Improving efficiency from project to project

3.1.1 Increased buying power in the market

In the development phase, the three-phase project strategy meant that the team at Dogger Bank was able to leverage economies of scale. Specifically, the increased buying power, due to the long-term, scaled-up and standardised nature of the contracting, enabled them to drive down costs for consumers whilst also strengthening their supply chain relationships. AA, previously of Equinor, highlighted the economic advantage of this approach:

> “The beauty is, when we see standardisation, we see cost reduction.”

More specifically, by producing a repeatable, long-term plan, the team provided a level of foresight and predictability to the market which was otherwise uncommon at the time. This gave their supply chain, including Hitachi Energy as the HVDC technology supplier, confidence that there would be consistent demand for materials and components. Mangat et al. suggest to this effect that when manufacturers and component suppliers are able to foresee higher production numbers of the same product, more investment can go into manufacturing technology, resulting in better quality, lower production cost and beneficial effects for supply chain competitiveness, manufacturers, and markets generally (Mangat et al., 2022).

3.1.2 Overlapped study and construction phases across projects

In the execution phase of the project, the three-phase strategy also created the conditions for overlapping efforts across different phases. LVV of Equinor said that knowing the site and HVDC design conditions would be the same for Dogger Bank A and B, they were able to conduct project studies (e.g. pre-engineering studies) for both stages simultaneously. This avoided additional spend on duplicating studies between projects—an issue prevalent in the offshore wind industry (OWIC, 2024)—and resulted in a shorter delivery window between projects. Similarly, given that Dogger Bank A and B were built side-by-side, they were also able to carry out construction on B by taking advantage of a team that had already developed all of the requisite skills during the initial construction phase for A.

Whilst Dogger Bank C connects to a different site in Redcar, Teesside, the similarity of the HVDC design and location also meant it was only a matter of tweaking and adjusting certain studies during the pre-engineering and system design phase. As LVV explained:

> “The majority of the learnings came from the efficiency of running many of the studies for A and B together, and the possibility to take a copy-paste approach from one phase to the others, standardising study methodologies.”

Fig 5: Onshore converter sites for Dogger Bank A and B

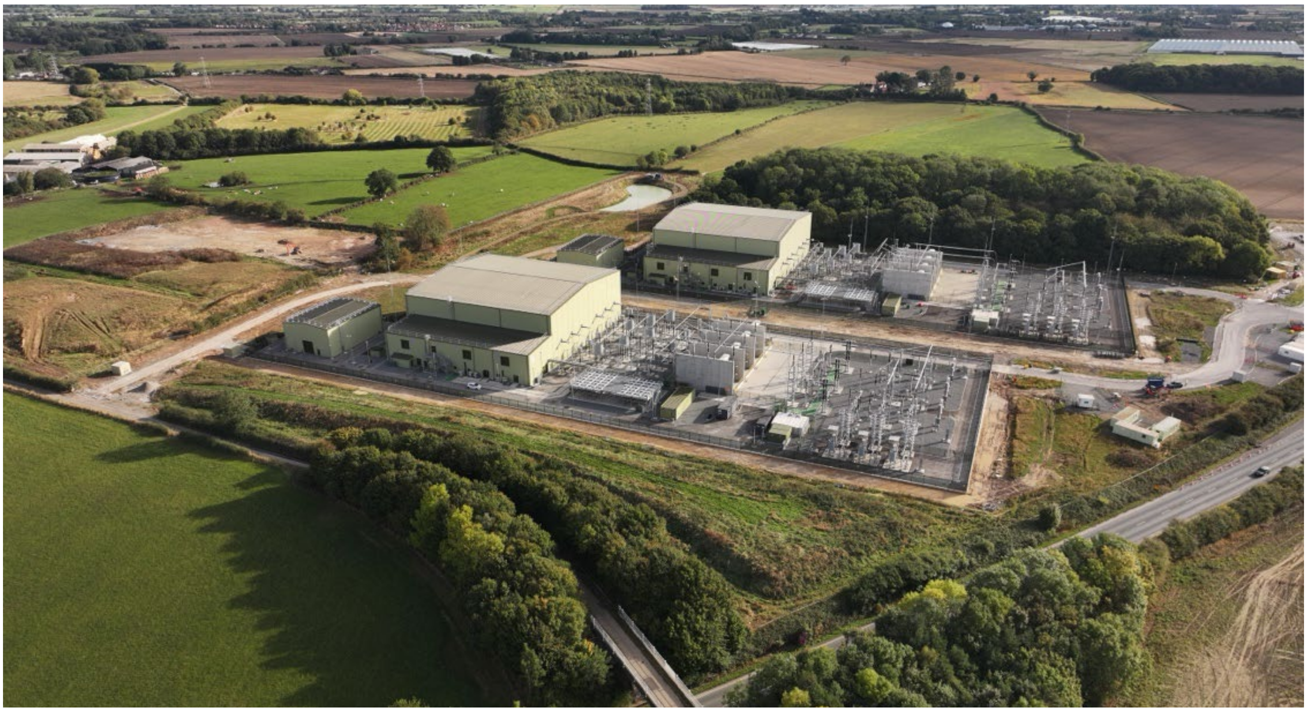

Image source: Dogger Bank Wind Farm

3.1.3 Improving efficiency from phase to phase

The project team was able to see substantial improvements in efficiency from one phase to the next. Interviews highlighted that the main improvements were seen in quality, since the need for fixes and interventions decreased as all the teams onsite (including contractors, construction workers and engineers) gained more experience. There was a noted improvement in installation time and operations, with the teams learning from the repeatability of the transmission design. This process also led to a significant reduction in the number of 'punches'—snags or small issues that unexpectedly arise and need to be fixed during construction—from phase to phase. LVV highlighted a substantial 60% drop overall:

> "[Punches] reduced significantly from A to B, and from B to C. We're talking about a reduction of approximately 60% in the number of punches throughout construction. We learn alongside our contractors what things need to be done to meet specifications."

GM of Hitachi Energy also suggested that when a developer comes forward with a portfolio of work, rather than looking "from project to project in isolation" it allows suppliers to focus on how they can maximise efficiency and get the most value from repeatability. He noted there had been "substantial improvements" from Dogger Bank A through to B and C based on learnings and experience from the first phase. In particular, GM felt that the "learning by doing" process, enabled by adopting the repeatable, standardised design was something which signposted how the industry should be executing projects in future:

> "Repeatability, standardisation, modularisation. Most of these texts that you see around how to deliver big projects, they all talk about building with Lego blocks. Get a bit that you know works, and repeat, repeat, repeat."

3.2 Collectively designing the innovative HVDC system

Once Hitachi Energy secured the bid to supply the HVDC system for the project, the design was then adapted to reflect project specific conditions through collaboration with SSE, Equinor and other involved parties. GM described this approach to designing the final HVDC package as a 'collaborative design alignment process':

> "The way I would look at it is a collaborative design alignment process. It wasn't R&D as such—we weren't developing a new product—the client placed a pre-engineering contract with us and a parallel pre-engineering contract with Aibel, and then the three parties developed the project specific solution for Dogger Bank."

In particular, this collaboration process centred around adapting the 'base solution' to meet the specific objectives and conditions at Dogger Bank. For example, project team members from across SSE, Equinor, and Hitachi Energy jointly carried out a number of in-depth study phases, including a feasibility study, concept study, and pre-engineering study. As LVV described this detailed design and study period:

> "The design came from a very strong collaboration between the companies, SSE and Equinor, along with Aibel and Hitachi, to develop this lean concept for the platform. The template had already been established, and the next step involved detailed engineering, where the specific parameters for all the components were developed, along with the necessary study work."

They also based this design process for each project on meeting four key requirements:

1. Ensuring the design had high reliability, availability and maintenance from one phase through to the next
2. Reaching the power transfer target of 1.2GW
3. Developing a lean concept design for the offshore platform and converter site
4. Meeting compliance requirements with the grid code

With regards to the offshore platform, for instance, the project team purposefully did not want to make any major changes across all three phases of the project. They decided to concentrate on getting the compact design—with 1.2GW capacity, a lean concept, high reliability and grid compliance—right first time. In line with these goals, they focused on how the efficiency of the offshore platform could feasibly be maximised whilst also building up reliability and ensuring that remote operation would, according to AB of SSE, be "just right" so that everything could be done from shore. This included choosing to work closely with engineers but also the operations team to make sure that the O&M strategy would be practicable.

From a supplier perspective, what interviewees at Hitachi Energy highlighted that they valued about the collaboration was the particularly flexible approach to the design process. For instance, GM of Hitachi Energy explained that sometimes, customers are liable to approach suppliers with a very detailed, rigid view of what they want in a way which can heavily influence the design process—e.g. only wanting to work with components and technology they've worked with in the past or having strong preferential ideas. In this case, SSE and Equinor only came with requirements which were absolutely necessary to meeting the project's goals, which allowed Hitachi Energy to draw from their expertise without externally imposed limitations. As GM put it:

> “There was a real focus on what was fundamental, as opposed to what was nice to have”.

AB of SSE shared a similar sentiment:

> “We worked throughout this whole process with Hitachi on design, making sure this fits our needs but utilising their expertise in HVDC systems.”

This collaborative design alignment process—built on supplier and developer teams working side-by-side and using complementary skills to set and meet the four key requirements for the HVDC system—was acknowledged by interviewees to have been an effective model for delivery.

3.3 Focusing on early risk mitigation and minimising interventions

Interviewees from SSE, Equinor and Hitachi Energy all highlighted the importance of early risk mitigation in the design process. Noting the scale and novelty of the project—as the first application of an HVDC transmission system for an offshore wind farm in the UK and furthest application from shore globally—extensive preparation went into the initial planning and development process. The target was to go into the construction stage having already considered any issues which, in the past, could have arisen during the early stages. GM stressed this aspect of the project development strategy:

> “I like to think that the fact that both Dogger Bank A and Dogger Bank B were delivered on schedule and that Dogger Bank C is also on track in execution validates this approach. [...] We did well to mitigate risk as much as possible before the execution process began.”

“Safe by design” was also described a guiding principle for the collaborative development process, to ensure that interventions were minimised as much as possible, and that any additional risks (for instance, related to working heights for workers or having the right equipment) were pre-emptively accounted for.

3.4 Developing and maintaining a collaborative working culture

The role of strong collaboration was invoked by all interviewees as an essential aspect of the project’s success, applying to the design of the lean HVDC system as much as to the project as a whole. Key decisions which supported a long-term collaboration include: (1) a commitment to open communication, (2) sharing a sense of ownership over the project, (3) building on pre-existing relationships and (4) signing a preferred supplier agreement.

3.4.1 A commitment to open communication

Interviews highlighted the fact that there had been a clear team commitment to maintaining a collaborative, respectful working environment. Team members from SSE Renewables, Equinor and Hitachi Energy described being able to openly share their thoughts, ideas, concerns and articulate different ways of thinking throughout the development process. LVV of Equinor emphasised the importance of talking through problems as a group to identify solutions:

> “Sometimes all you need is people to talk to each other. Chances are not everyone is going to agree, so you need to build the right culture so that no one is afraid to speak their mind, and so that everyone is open to having a discussion together. That was really good with the team that we had.”

SS and GI of Hitachi Energy also emphasised the key role that transparency played in maintaining a long-term relationship between the developer and supplier teams:

> "Truth and transparency. Transparency means you are not hiding anything. You are telling the truth, but also sharing everything—good or bad—transparently. The client [SSE and Equinor] is fully aware and always ready to help us. They also start sharing transparently, so we know the problem in advance, rather than at the end when we have no time."

LVV of Equinor also expressed that a concerted effort was made to ensure that, regardless of differences in opinion, team members would "sit at the same table" and work together to find a compromise if an issue arose:

> "As a client and a supplier, there are some differences with regards to what each party is looking for [...] but what was particularly special about this group is that, regardless of the difference of opinions, we would always sit down at the same table, either remotely or in person, to lay out what the concern was."

The longevity of the project, which had a nine-year gestation period, was also mentioned as a factor which showcased the team's resilience and dedication to working together. The three parties continued to engage and collaborate through periods where it would have been simple to say, "forget this, this doesn't make sense for us". A shared understanding that what they were working on made sense—and was feasible—and a shared passion to keep going in spite of delays and setbacks, helped the project team "keep going" when it faced setbacks and delays during the development phase.

3.4.2 Sharing a sense of ownership over the project

Interviewees emphasised that, throughout the development and execution of the HVDC system, it felt as though they were working as one team. This sense of mutual ownership over the project was in part a result of how leadership responsibilities were distributed throughout the project. Equinor led the development of the transmission solution up to the start of project execution and construction, at which point SSE took over as operator to construct the system, with leadership then transferring back to Equinor for O&M. The absence of one consistent leading party created the sense that it was one team working towards a shared goal. As GM of Hitachi Energy stated, speaking about the design process, it wasn't about one any team "trying to put their individual stamp on it".

In this sense, GM described Dogger Bank as a forerunner of strategies and approaches which are becoming more common within the industry. He explained that the market was moving away from transactional relationships—with long bidding processes typically jumping into execution contracts immediately on conclusion—and towards more collaborative ones with earlier contractor engagement and selection followed by longer co-development periods.

3.4.3 Building on pre-existing relationships

SSE, Equinor and Hitachi Energy had previous experience working in a collaborative capacity. GM noted that Hitachi Energy had a longstanding relationship with Equinor, that they had worked with SSE's network colleagues to deliver the Caithness Moray project, and that they had been working closely with Aibel, who designed and built the unmanned platform, for over a decade. All of these pre-existing relationships made initial engagement easier. For instance, whilst Hitachi Energy and Aibel had a formal, strategic partnership arrangement in place, on a day-to-day basis this longstanding relationship had allowed them to adopt a more informal working style. As PS of Hitachi Energy described:

> "[With Aibel] We pick up the phone and speak directly to the engineers and solve issues and initiate interesting studies [...] so we have both a formal and informal relationship with them, and I think that's the key to the success – we can shortcut the formal way and be much more vigilant and quick in our decision process."

3.4.4 Signing a preferred supplier agreement

SSE and Equinor had already signed a preferred supplier agreement with Hitachi Energy, so that when the CfD process was complete and the project was approved in 2019, work was able to start immediately. At the time, signing a preferred supplier agreement wasn't common in the industry, and it allowed them to move on to construction more quickly than if they had waited to secure the CfD and then run a fresh tender round. By signing the initial agreement, they were able to strategically plan the capacity and resource availability to start working on day one.

3.5 Summary of successful practice

As explored through interviews, these four key strategies—adopting a three-phase delivery approach with a standardised design, collectively designing the HVDC, prioritising early risk mitigation and maintaining a collaborative, open working culture—enabled the team to come together and deliver a project which was "just right" first time.

Applied from the early days of the project, these strategies also created a foundation for addressing unpredictable challenges as and when they arose. With a complex, large-scale engineering project such as this one, "there are always things that go wrong" and having these strategies in place allowed the team to adapt and problem-solve more flexibly. In the following section, these challenges are explored in more detail, and where applicable, illustrative examples of how the team strategically adapted are also provided.

Section 4: Challenges

This section is divided into three types of challenges: project planning challenges, macroeconomic project execution challenges, and local, onsite project execution challenges. This first sub-section looks at the challenges associated with Development Consent Orders (DCOs) and permitting timelines. The second looks at the impacts of the COVID-19 pandemic, the war in Ukraine and the global energy transition. The third explores local and onsite challenges related to distance, weather conditions, vessel procurement, labour and skills, and cooperation with third-party developers.

4.1 Project planning challenges: permitting and DCOs

It took many years between the seabed being leased for Dogger Bank and construction to start. This was partly due to the nascent state of the industry—there was a lack of established planning frameworks in place—and partly due to the lengthy permitting process. In the UK, it takes a long time for Nationally Significant Infrastructure Projects (NSIPs) to receive a consenting decision. The timespan for Development Consent Orders (DCO), for instance, is intended to be less than two years but often stretches far beyond this, and the documentation involved in the consents process often runs to 'tens of thousands of pages' (DESNZ, 2024a). SS of Hitachi Energy explained that whilst Dogger Bank had the "luxury of time" which current projects do not, it still took almost four years to get the DCO. For the projects that have since followed, this consents process is largely unchanged, with developers still needing to start effectively from scratch each time they bid for a new project.

The Department for Energy Security and Net Zero (DESNZ) have stated that for offshore wind, where lead times for projects are often more than a decade, accelerating delivery has become 'exceptionally critical' (DESNZ, 2024a). Elongated timelines exacerbate the risk of not being able to deliver 43-50GW offshore wind power by 2030, whilst also increasing the likelihood of projects beginning construction with outdated technology in their plans (IRENA, 2023). As in the case of Dogger Bank, which had to navigate the impacts of COVID-19 and the war in Ukraine, the longer the gestation and permitting periods, the higher the risk that the wider macroeconomic environment will shift towards 'increased commodity prices, cost of capital, labour, and logistics' (GWEC, 2024).

4.2 Project execution challenges: macroeconomic and geopolitical

Interviews revealed several macroeconomic and geopolitical challenges that impacted project execution, including challenges related to the COVID-19 pandemic, the war in Ukraine and the global energy transition.

4.2.1 The COVID-19 pandemic

The switch to remote working introduced new challenges when construction began in 2020, particularly when it came to ensuring the quality of components. On a global scale, remote working was a challenge because the supply chain for Dogger Bank's HVDC system was extensive—the offshore platform, for instance, first had to be assembled in Thailand, then transported to Norway for final construction, and then installed in the North Sea. On a local scale, the switch meant that the engineering team were unable to go into the factories in person to do acceptance testing with the contractor, which is typically what provides an in-depth view of the manufacturing process.

The project team adapted in a variety of ways: they used more videos to carry out inspections of the components, increased the amount of detail requested in documents, used drones, and had regular online meetings. They also focused more on identifying and mitigating possible risks ahead of time. AA, previously of Equinor, also stressed that working through the pandemic had required substantial resilience:

> "One of the things I immediately want to highlight is the resilience of the people and the project, to make sure that during a very challenging, unprecedented time, the project was still able to progress."

4.2.2 The war in Ukraine

In 2022, the Dogger Bank project was impacted by Russia's invasion of Ukraine, which caused the 'largest commodity shock' since the 1970s and led to a surge in the price of steel and other commodities (BBC, 2022). Specifically, this surge was due to disruptions in supply chains cause by the conflict, leading to a shortage of raw materials like iron ore and coking coal. Whilst price increases impacted all renewable generation sources, capital-intensive sources like offshore wind energy were relatively more affected (Musial et al., 2023). As AB of SSE explained, the team had to work closely with the subcontractors to adapt:

> "We've had to manage that with the subcontractors and with the supply chain, making sure those impacts aren't felt by them, but trying to protect the business case at Dogger Bank in a responsible way"

SS of Hitachi Energy talked about how the war in in Ukraine had impacted the production of circuit boards. Ukraine produces the majority of world's neon gas, which is needed to print circuit boards, so when the war began, production came to a direct halt, creating a "huge disruption". The standardised delivery approach did however minimise the impact of these production delays—as SS explained, despite these supply chain issues, they could still perform testing and install cables (even without putting in all the circuits) in Dogger Bank A and later "copy paste the results" for Dogger Bank B and C. As SS and GI said:

> "That was a challenge, however, we mitigated it because we had A, B, and C. So even if the complete test wasn't done, it was done in A. The work didn't fully stop—it was still moving. Then we could just copy-paste the result."

4.2.3 The global energy transition and supply chain squeeze

The global energy transition has created a supply chain 'squeeze', where the growing pipeline of renewable projects has had a significant impact on the availability of components and commodities, and subsequently, the length of time projects take to complete. This has led to project delays and rising project costs, most notably in Europe. For instance, by 2027, all regions, except for China, are expected to face the bottlenecks in the offshore wind supply chain (GWEC, 2024).

For example, one interviewee from Hitachi Energy highlighted that the transformers for the onshore converter stations at Dogger Bank A, B and C took 18 months to arrive, and that in the time since, the uptick in projects means that a similar project would now need to wait five years. DESNZ's UK Renewables Deployment Supply Chain Readiness Study specifies that supply chain issues are the most severe for the offshore wind and offshore wind transmission sectors, and that the components facing the biggest capacity constraints include HVDC cables and converter stations, as well as installation vessels and ports (DESNZ, 2024b).

Whilst this is a challenge which has accelerated in the time since Dogger Bank secured its components, the standardised, phased approach represents a strategy that nonetheless helped to improve the procurement process and time. Standardising the HVDC system design, and procuring the same components over three separate phases provided the supply chain with a more transparent, long-term view of what would be coming down the pipeline.

4.3 Project execution challenges: local and onsite

Building the UK's first and world's largest HVDC offshore wind farm presented a number of local and onsite challenges. The scale of the Dogger Bank project meant that the team had to navigate vast distances, as well as manage unique weather conditions, vessel procurement difficulties, labour and skills constraints, and cooperation with third-party developers.

4.3.1 Distance-related challenges

With Dogger Bank A and B located 130 kilometres from shore and Dogger Bank C 196 kilometres from shore, Dogger Bank Wind Farm as a whole represents the furthest installation of an HVDC system for an offshore wind farm in the world. This being the furthest application added new challenges, specifically during the construction phase. AB of SSE explained that the journey from shore to the offshore site typically takes 12-18 hours, meaning that to compensate for the length of the journey, construction teams had to be sent off for two weeks at a time. Any mistakes therefore became much more costly e.g. if any tools were accidentally left behind, this had a "massive impact" on cost and construction efficiency. AB also explained that the distance from shore made it more difficult to maintain constant, meaningful contact with the team.

> "With being that far offshore, the time and cost to actually fix [issues] is massive. You have to deploy vessels. You have to deploy teams who are out there for two weeks at a time. It might be something that just takes someone fifteen minutes when you're onshore."

Minimising interventions as much as possible therefore became a central part of the project execution strategy. This included, for example, creating a feedback loop to give messages back to factories supplying or building equipment like the jacket or superstructure for the platform to pre-empt and avoid work later needing to be carried out offshore. It also included looking at new ways of mitigating risk, for instance, minimising the amount of working at height needed by replacing what would traditionally have been ladders with stairs, and putting in windows so that the condition of components could be seen more easily.

4.3.2 Unique weather conditions

The Dogger Bank Zone is a sandbank, so whilst located far offshore, it's also shallow—ranging in depth from 13 to 58 metres below sea-level (Joint Nature Conservation Committee, 2024). This sandbank structure also influences the height of the waves, which can reach staggering heights of up to five metres. Long 'fetches'—wind blowing from both North and South—mean the waves gain strength and size as they travel across the open sea before reaching the sandbank, in turn increasing the risk of damage to the offshore converter platform.

The project team were made aware of these unique risks through communication with other developers working in the Dogger Bank Zone, who shared with them information about the wave phenomena and sandbank conditions. They also conducted additional studies ahead of time to adapt the design (e.g. changing the turbine design) and make it better suited to the conditions.

4.3.3 Vessel procurement

The team faced challenges due to the fact that only three specialised vessels in the world could install the offshore converter station for the HVDC system. For example, the vessel initially secured to install the HVDC system suffered a crane failure, forcing the project team to track down and arrange access to one of the two remaining vessels. AB explained that, although they were able to eventually access a replacement vessel, they had to manage additional scheduling complications because it could only be used in a way that aligned with its existing programme and commitments.

Fig 6: Second HVDC offshore platform being installed at Dogger Bank B

Image source: Dogger Bank Wind Farm

4.3.4 Labour and skills shortages

AB of SSE explained that with the rise in offshore wind projects globally, there had been an influx of new recruits into the industry. However, there was still a “stretch in capacity” due to the learning curve associated with training and the size of workforce required by the industry.

For instance, in the UK, the lead time for new entrants into the sector through apprenticeships can be up to six years (HEY LEP, 2023). To this end, AB commented that the downturn in oil and gas had been beneficial to the project, because SSE was able to take advantage of available workforce with transferrable skills.

SS and GI of Hitachi Energy also stressed the role of regional limitations in the labour contracting process. Although the project team had contracted the same subcontractors for Dogger Bank A and B (with associated benefits as discussed above) it was not possible to relocate the same subcontractors to Dogger Bank C:

> "What we found is that contractors are not only [selected] based on their skill, but also on the region where they work. So the intention was to get the same contractor, with the same manpower, to go to Dogger Bank C during the tech operation. But the subcontractor did not agree to go there."

4.3.5 Third-party cooperation and information-sharing challenges

While Net-Zero targets are pushing the offshore wind industry in the UK to work together in more of a collaborative capacity, competition is still central to how the industry operates; largely due to the CfD bidding process, there is still a 'strong disincentive' to share information between competitors (OWIC, 2024). However, with the influx of offshore wind projects driving onshore connection sites for offshore wind farms closer together, competing developers will increasingly need to find ways of cooperating on project delivery while simultaneously protecting their individual business case.

When the team was working on the onshore converter site for Dogger Bank C, for example, they had to navigate a relationship with RWE, who were building Sofia Wind Farm—another HVDC offshore wind farm in the Dogger Bank Zone—and who had their onshore converter site immediately adjacent. Rather than working in isolation on their individual projects, which is the typical procedure among competing developers, the teams decided to capitalise on the advantages of working together by cooperating on several aspects of project execution.

Firstly, they worked together on local stakeholder engagement, recognising that it would be more effective and simple if they "put aside their corporate identities" and spoke to local coastal communities about both projects together. RL of SSE highlighted that Hitachi Energy also contributed, going beyond what was outlined in their contract to increase the impact of stakeholder engagement. This cooperation between the Dogger Bank team and RWE also helped to minimise disruptions to the community. For example, knowing that there would be road closures for the delivery of transformers for both Sofia Wind Farm and Dogger Bank C, the two developers jointly created and shared a delivery programme with the local community. By developing the programme together, they were able to coordinate so that there would be a few weeks' break between deliveries. This approach also helped to amplify the programme's overall visibility and impact.

Secondly, the Dogger Bank team worked with RWE on some of the contracting for the civil engineering works, which was a new experience for both parties. Using a joint civil contract, they were able to save on disruptions and reduce the amount of work done to the shared compound, while also creating new professional relationships. This process was not without its complexities, including having to consolidate differences in methods and quality assurance, but ultimately it created the conditions for both parties, and the local community, to experience the delivery of the projects in a more positive, streamlined way.

Fig 7: Transformer being delivered to Dogger Bank C in Teesside

Image source: Dogger Bank Wind Farm

Section 5: Discussion – revisiting lessons from Dogger Bank's transmission journey

Successfully delivering Dogger Bank took many years of collaboratively developing a plan "almost from scratch" at a time when the market was less established, HVDC technology at scale in an offshore wind environment was still maturing, and flagship schemes for supporting offshore wind (e.g. the CfD and OFTO regime) did not yet exist. From the Forewind Consortium's initial planning and engagements in the early 2010s through to the current day—where only a few years are left before the project is fully operational—the team had to evolve alongside these industry changes. This included adapting to a range of regulatory, macroeconomic and local challenges—several of which have become more urgent in the time since Dogger Bank was first being developed.

Looking forward, experiences from Dogger Bank provide first-hand examples of how the industry could be working today to accelerate the pace, scale and quality of offshore wind projects in the UK. The main strands of the overall successful strategy include, as aforementioned:

- Adopting a phased strategy with a standardised HVDC system design
- Collectively designing the innovative HVDC system design
- Focusing on early risk mitigation and minimising future interventions
- Developing and maintaining a collaborative working culture

Building on these points, the role of strong collaboration was invoked by all interviewees. Whilst this is explicitly addressed in section 3.4, it stands out as an essential aspect of all four strategies, and applies as much to the design of the lean HVDC system as it does to the project as a whole. Collaboration at all levels, including between the three partners, but also across different levels of the supply chain, and even between competing developers, helped to simplify the delivery process.

The following sub-sections consider how these strategies, as well as challenges and lessons from throughout Dogger Bank's transmission journey, fit in with broader discussions about offshore wind in the UK's energy transition. Specifically, they analyse challenges related to grid integration, HVDC supply chain vulnerability and developer competition, exploring how experiences from Dogger Bank, when adopted, could be used to steer the UK's offshore wind industry towards:

- Greater adoption of HVDC technology and projects
- Strong, stable domestic HVDC supply chains
- Resilient, integrated networks
- Long-term, collaborative business partnerships

5.1 Towards an offshore wind industry with greater adoption of HVDC technology

The pace and scale of offshore wind growth means HVDC technology and infrastructure will play a pivotal role in achieving 2050 Net-Zero targets (National HVDC Centre, 2021a). In particular, HVDC technology can provide solutions that simultaneously improve grid resilience and stability, enable developers to build more strategically located and connected wind farms, and reduce costs associated with resources and infrastructure.

HVDC was the chosen technology for the transmission system at Dogger Bank for several reasons. The first was related to scale and distance of the project, with all three sites located between 130-190 kilometres from shore, and the second was related to the additional benefits HVDC provides over HVAC. This includes lower losses, a smaller right of way, no limits on distance, and ancillary services (Rahmqvist, Monge & Sandeberg, 2023). These ancillary services, which are still being trialled and tested, include active and reactive power control, precise power flow control, protection of the grid and wind farm against transients, black-start capabilities and damping of area-wide power oscillations (ibid).

Looking forward, HVDC is also expected to play a central role in enabling more complex, integrated wind farm configurations to be constructed. This includes emerging and future applications such as multi-terminal and multi-infeed offshore wind farms, energy islands, Offshore Hybrid Assets, and innovative technologies like Energy Storage Systems (ESS). AA suggested to this extent that Dogger Bank could be viewed as the "first step" in this process towards these more complex configurations:

> "Interconnected HVDC systems—that is the future. Dogger Bank represents the first step in our story."

Now, despite evidence of the advantages HVDC presents for offshore wind farms, it has, until recently, been an underutilised technology in the UK. One reason highlighted during interviews was that past "techno-commercial" challenges have dissuaded developers from opting for HVDC. As AA suggested, part of the economic model for an offshore wind project also involves considerations for how quickly power—and therefore revenue—can be generated. Consequently, although there is a 'breakeven' distance to determine whether a project should use an HVAC or HVDC transmission system, developers have commonly been swayed to opt for HVAC simply because it has a more established, varied and stable supply chain. As AA put it:

> "If you want an HVDC system, but your supply base is saying it's going to take a year longer than giving you an HVAC system [...] that might tip your project decision to go for the less efficient HVAC solution."

With Dogger Bank only a few years away from completion (and a number of other large-scale offshore HVDC projects following closely behind e.g. Hornsea 3 and Sofia Wind Farm), the UK has now developed a foundation of skills and expertise which should help to overcome this associated techno-commercial barrier. In particular, the blueprints for copy and pasting HVDC designs are now much more readily available. AA spoke to this growing domestic expertise:

> "As a country, we're building up this experience and this knowledge, which will propagate across the next round of projects as well [...] The first project is always going to be hard to build [...] but the second one's going to be easier and we'll have more people who've learned from it and just keep on keep rolling them out."

The HVDC Centre has also suggested to this extent that the UK should leverage its existing expertise in interoperability, wide-area control and supervisory control, system monitoring, and asset management to continue to drive domestic innovation in HVDC (National HVDC Centre, 2021b). As part of this effort, they also recommend increasing domestic investment in R&D for HVDC, e.g. channelling funding towards universities and doctoral centres, so that the grid-supporting services can be further researched and exploited. This includes concentrating R&D efforts on carrying out factory testing and conducting grid-scale trials of HVDC ancillary service control schemes (National HVDC Centre, 2021a).

5.2 Towards an offshore wind industry with strong, stable domestic HVDC supply chains

To ensure the UK's current and future HVDC project pipelines are able to procure the necessary components and equipment, as well as provide developers with the confidence to opt for HVDC projects, efforts will need to be made across industry and government to ensure stable growth of the domestic HVDC supply chain. As it stands, it is estimated that by 2050, integrated offshore networks in the UK will need additional HVDC infrastructure including at least 5000 km of HVDC cables and 40 offshore and onshore converter stations to achieve the connection of up to 75GW of offshore wind (National HVDC Centre, 2021a). This scale of network growth and development has not been seen in the UK since the 1960s (ibid).

Whilst the Dogger Bank team did not face as many procurement challenges as would be expected for a similar project today—largely due to the recent explosion in renewable energy projects globally—the impact of macroeconomic and geopolitical events throughout the project highlights the ongoing fragility of offshore wind supply chains, particularly where HVDC-related components are concerned. The Global Wind Energy Council suggests that across all major component types, including HVAC transformers, HVDC converters, high voltage cables and support structures, there is a large shortage of both manufacturing capacity and qualified resources (GWEC, 2024). Additionally, in the UK, the CfD process risks further exacerbating supply chain bottlenecks. Since developers wait until they receive the CfD award before placing firm orders, they tend to be 'strongly motivated' to choose suppliers who can deliver on a short-term basis (Pick, 2023). This means suppliers who might need several years in new or scaled-up facilities to be able to service those orders are unable to compete (Pick, 2023).

One approach to addressing these supply chain bottlenecks and constraints as an industry is standardising designs. Literature has continuously highlighted the importance of standardising offshore wind designs, with increasing discussion about standardising HVDC systems (GWEC, 2024; Andrey et al., 2022; 2021; Mangat et al., 2022; Silverman & Glatz, 2024). However, offshore development in the UK has still tended to be 'fixated on projects', with challenges continuously solved through a process of project-to-project optimisation (Pick, 2023). Dogger Bank showcases the value of shifting away from this iterative process in favour of a more collaborative, standardised design process. As AA emphasised:

> "One of the messages here is that we've created a standard, we've created a copy and paste concept. [...] In theory, you've done all the hard work [...] so every single time you duplicate or replicate that design or manufacture that concept, the overall effort has been optimised. So there's so much value in the fact that A, B and C have been developed in that way."

During the transmission journey, this "copy and paste" concept provided the supply chain with a clearer view of what was coming down the pipeline. Other advantages of this approach include being able to overlap project study and construction efforts, and reduce 'log jams' during different phases of development such as consenting, interoperability management, and testing and commissioning (National HVDC Centre, 2021b). Standardisation also helps to address some of the labour and skills supply constraints the sector faces, since workers entering the sector then only need to develop the requisite skills once. As GI explained, this is particularly important for the HVDC sector, which in recent years has transformed from a niche market to one growing at an unprecedented rate:

> "If we want to be able to deliver more, we need to be efficient, but it's not very easy if a team today consists of 8% of people that have not been employed less than a year. So that's a challenge for the industry [...]. If you do standardisation, that will also become easier."

What could a standardised domestic HVDC design look like?

There are competing ideas about what a national or global standard for HVDC transmission system designs could look like. When it comes to developing standardised components, for instance, research highlights two potential approaches—either creating multi-vendor standards, to continue enabling competition and ensure compatibility of different manufacturer components, or creating single-vendor standards, and reducing risks of interoperability (Silverman & Glatz, 2024). For example, the EU's InterOPERA initiative, due to be complete by 2028, has been established to reduce technological compatibility risks by specifying multi-vendor standards and developing equipment specifications (ibid).

In Europe, where there is generally less supply chain fragmentation for HVDC components, developers and Transmission System Operators (TSO) are largely coalescing around 525 kV HVDC platforms allowing for connection of 2,000 to 2,400MW offshore wind farms (Silverman & Glatz, 2024). For instance, TenneT, the TSO in Northern Germany and The Netherlands, has set a standard 2GW HVDC solution and involved manufacturers ahead of required delivery to help develop the technology and give confidence in the performance ahead of implementation (National HVDC Centre, 2021b). AA advocated in favour of the same 2GW standard in the UK, to improve interoperability and "take advantage of Dogger Bank":

> "We're advocating in the UK for the adoption of the two-gigawatt standard as well. All of this hard work, including taking advantage of Dogger Bank and putting in the necessary engineering effort, hopefully allows us to leverage the progress made by TenneT and suppliers. The goal is to simplify things by essentially saying, "I'll have one of those, please—just pick it off the shelf". This would significantly reduce the amount of engineering work required."

5.3 Towards an offshore wind industry with resilient, integrated networks

The increase in large-scale renewable energy projects like Dogger Bank, coupled with the decrease in traditional power sources, will introduce complex interactions in the UK's electricity grid. The challenge of grid integration has therefore become a recurrent theme in discussions about the transition to Net-Zero. If poorly managed, the integration of renewable energy sources will have a negative impact on the stability and resilience of the grid—leading to possible blackouts and voltage dips.

To this end, accelerating the rate at which renewable energy projects are completed will also need to be accompanied by an increase in upgrades to the grid. It is the case, for instance, that transmission development tends to operate on a slower timeline than renewable projects (IEA, 2025). This has been true for the UK, where regulations have historically prioritised minimising short run consumer costs and not promoting anticipatory investment (Pick, 2023). Recent changes, signposted by the Transmission Network Review and Holistic Network Design, propose adopting a more integrated approach to network design. This features plans to shift from a reactive to proactive design framework, which would include upgrading grid infrastructure in line with a comprehensive understanding of the renewable project pipeline. This approach, if correctly applied, could help to reduce costs, shorten development timelines, and increase grid resilience (Pfeifenberger et al., 2024).

While the scale of this network challenge goes beyond the scope of what the team at Dogger Bank had to contend with, interviewees discussed opportunities for reducing the risk of negative grid interactions from a developer perspective. For example, LVV described how, among the industry, there is a lack of consensus when it comes to conducting grid interaction studies. The current process involves a developer, National Energy Systems Operator (NESO) and Transmission System Operator (TSO) defining the scope of the study and determining which cases should be investigated in detail, based on whether there is risk of interaction. In short, there is no industry-wide consensus on what grid interaction studies should look like, including no standardised analysis methods or success criteria. LVV explained that this lack of framework made it "very challenging" for developers and resulted in lengthy study scopes that demanded significant resources, large amounts of data, considerable time, while also increasing risk:

> "The challenges that we've been having—and which are going to become more and more relevant as we integrate more renewables and more HVDC links—is that there's no standardisation, [...] there's no clear path in success criteria, which makes it very challenging for us to implement that into projects and protect ourselves from future changes."

To integrate more renewable energy sources and HVDC systems in the grid while effectively mitigating the risk of grid instabilities, LVV expressed that industry and relevant stakeholders, including NESO and TSOs, should come together to standardise analysis methods and success criteria for grid interaction studies, as well as align on a process for safely sharing data.

5.4 Towards an offshore wind industry with longer term, collaborative business partnerships

It was noted by several interviewees that, in the years since Dogger Bank had been awarded the CfD, the industry as a whole had become more cooperative. It was more specifically suggested that the industry had transformed from a market dominated by short-term, transactional relationships to more long-term, increasingly collaborative partnerships. This is seconded by the literature, which highlights that developers, especially in Europe, are turning to longer term framework agreements, typically lasting up to five years (Silverman & Glatz, 2024).

At Dogger Bank, the long-term partnership between SSE Renewables, Equinor and Hitachi Energy provided several advantages. Firstly, it provided Hitachi Energy, as the supplier, with a long-term view of what was coming down the pipeline. Secondly, it allowed the Dogger Bank team to develop a more informal collaboration style, build trust, and in turn problem-solve more effectively. Other elements that contributed to maintaining a collaborative spirit throughout the many years of working together included sharing a sense of ownership over the project, building on pre-existing relationships, and actively creating a collaborative working culture.

This long-term partnership also followed a 'collaborative design alignment process' for the HVDC system, which involved supplier and developer teams working side-by-side and using complementary skills to meet the key requirements for the transmission system. The key principles of this process included building on the teams' respective areas of expertise, delivering on elements of the design that were fundamental rather than “nice to have”, focusing on early-stage risk mitigation, and ensuring communication was open, transparent and respectful. Adopting these and similar collaborative principles will be key for developing future HVDC projects in the UK, which will feature more integrated and interconnected designs, such as multi-project, multi-terminal, and multi-infeed scenarios, and require collaboration between multiple stakeholders (National HVDC Centre, 2021a).

Additionally, while it may be the case that the industry as a whole is becoming more cooperative, and that approaches taken at Dogger Bank may reflect a broader trend, it has also been noted that competition between developers continues to pose an issue to meeting the UK’s offshore wind targets. Due to the inherently competitive nature of the CfD bidding process, collaboration and information-sharing between developers is often still inhibited (OWIC, 2024; Pick, 2023). When it comes to meeting ‘big picture’ targets like Net-Zero 2050, the HVDC Centre specifies that the UK cannot continue as it has in the last 20 years, with individual developers, OFTOs and manufacturers innovating and delivering in isolation (National HVDC Centre, 2021a).

Dogger Bank highlights the multi-faceted value of collaborations which extend beyond the scope of a single project. In particular, the shared initiatives between the Dogger Bank team and RWE highlighted that it is both productive and possible for competing developers to cooperate without forgoing the advantages of competition. By collaborating on local stakeholder engagement initiatives, exchanging information about wave conditions and even sharing contracts, both offshore wind projects advanced in a more resource-efficient, cost-effective and community-oriented way. Future projects should, where applicable, explore opportunities to share research or even coordinate onshore/offshore transmission construction and engagement activities to ensure similarly positive and productive delivery.

Section 6: Policy recommendations

Based on challenges and successful practice from Dogger Bank's transmission journey, this final section presents a series of policy recommendations for supporting sustainable, accelerated growth of offshore wind projects in the UK. This includes recommendations targeted at policymakers, as well as recommendations for stakeholders in the offshore wind industry.

6.1 Recommendations for policymakers

- Introduce a maximum permitting time for offshore wind projects: The government should consider ways to streamline permitting and DCO timeframes, for instance by simplifying requirements, particularly for locations with lower environmental risks, and by introducing a maximum permitting time for offshore wind projects. The Global Wind Energy Council proposes mandating a maximum time of three years (with additional time allowed under extraordinary circumstances) and granting deemed consent if permitting authorities fail to meet the agreed timeframe (GWEC, 2024).
- Involve statutory consultees earlier in the project approval process: Earlier involvement from statutory consultees would give developers more foresight in the permitting process, allowing them to streamline the application process by addressing potential roadblocks and risks ahead of time.
- Increase domestic investment in R&D related to HVDC: To leverage the expertise and skills the UK is building up in HVDC, the government should consider boosting investment in R&D for HVDC technology, particularly where this concerns potential ancillary services and technologies with potential synergies, such as ESS. The HVDC Centre suggests channelling investment towards universities and doctoral centres, to develop early designs, carry out factory testing and conduct grid-scale trials of HVDC ancillary service control schemes (National HVDC Centre, 2021a).
- Increase grid capacity to support integration of offshore renewable energy sources: To prevent grid infrastructure from becoming a bottleneck, the government should continue its work developing a proactive network planning framework. Recommended measures include carrying out regular assessments of transmission network capacity needed to support offshore wind projects, installing grid upgrades in tandem with offshore developments, ensuring that regulatory risk assessments enable anticipatory investments and considering compatibilities with emerging technologies such as energy storage (Pfeifenberger et al., 2024). This recommendation aligns with the objectives of the Strategic Energy Planning (SEP) process being developed by NESO, which should be fully and robustly delivered to ensure timely, coordinated grid infrastructure that supports delivery of offshore wind targets. Increasing grid capacity in a systematic, integrated way could also help to reduce costs and development timelines, as well as increase grid resilience.
- Support growth and stability of domestic HVDC supply chains through standardisation: To address HVDC supply chain constraints, accelerate the pace at which components are produced and increase interoperability, the government should support the development of standardised designs for HVDC systems. For instance, it could seek alignment with the European market in taking a programmatic approach to HVDC offshore network delivery similar to that adopted by TenneT.

6.2 Recommendations for the offshore wind industry

- Standardise HVDC system designs across multiple projects: Developers should look to transition away from optimising individual projects and towards standardising designs across multiple projects or phases. Dogger Bank exemplified the benefits of using a scalable, “copy paste” approach, including cost savings, rapid improvements in efficiency and increased resilience against macroeconomic and onsite challenges.
- Develop standardised grid integration study methods: To effectively mitigate the risk of negative grid interactions and shorten study timelines and costs, NESO and developers should collaborate to reach consensus on a standardised method for conducting grid interaction studies, as well as develop a set of harmonised success criteria that ensures consistency and reliability across different projects. For this to be most effective, a safe data-sharing process would need to be developed through collaboration between developers, OEMs and TSOs, e.g. in order to share models which accurately represent real system dynamics.
- Adopt a ‘collaborative design alignment process’ with suppliers and other involved parties: During development phases of an offshore wind farm, a collaborative design alignment process—founded on open, transparent communication, respect for each party’s different areas of expertise, and a focus on delivering fundamental design features—helps to drive forward the design process and study phases in a more coordinated, focused way.
- Prioritise long-term, collaborative business partnerships: Entering into longer-term business partnerships can provide mutual benefits for suppliers and developers. For suppliers, long-term contracting provides visibility and foresight into procurement needs years ahead of time, and for developers, it reduces the likelihood of delays procuring necessary components and equipment. Factors that enabled the Dogger Bank team to successfully maintain a collaborative partnership over many years include signing a preferred supplier agreement, contracting across multiple project phases, sharing leadership responsibilities, and operating as one team when addressing development, design, and execution challenges.
- Increase information and knowledge sharing between third parties, e.g. developers working separately on the same zones or sites: The competitive nature of the offshore wind sector can inhibit collaboration between developers. Where relevant, developers should look for opportunities to share research, coordinate onshore/offshore transmission construction activities and even jointly carry out local community engagement activities. Experiences from Dogger Bank highlight that it is both productive and possible for competing developers to cooperate without forgoing the advantages of competition.

Annex

Box 1: List of Interviewees

- Ajai Ahluwalia (AA) – Head of Supply Chain at Renewable UK, previously Technical Lead at Equinor for Dogger Bank's HVDC transmission package
- Alan Borland (AB) – Project Director at SSE Renewables
- Elin Rahmqvist (ER) – Global Product Specialist for HVDC systems at Hitachi Energy
- Grant McKay (GM) – HVDC Sales Lead for Northern Europe at Hitachi Energy
- Goran Isacsson (GI) – Project Director at Hitachi Energy
- Lila Vazquez Villamor (LVV) – HVDC Package Manager and Company Representative at Equinor for the HVDC system and supply chain contracts for Dogger Bank A, B and C
- Peter Sandeberg (PS) – Global Product Manager Hitachi Energy
- Rachel Lawrence (LR) – Community Engagement Manager at SSE Renewables
- Sri Singh (SS) – Local Project Manager at Hitachi Energy

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