Hornsea Project Four

Greenhouse Gas Footprint Assessment

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Glossary of Terms

Term	Definition
Carbon Dioxide Equivalent (CO_2e)	Carbon dioxide equivalent is a term for describing different greenhouse gases in a common unit. The unit takes the different global warming potentials of greenhouses gases into account. CO_2e is signifies the amount of CO_2 which would have the equivalent global warming impact.
Cradle-to-factory or cradle to (factory) gate	A term which includes the extraction, manufacture and production of materials to the point at which they leave the factory fate of the final processing location
Energy balancing infrastructure (EBI)	The onshore substation includes energy balancing Infrastructure. These provide valuable services to the electrical grid, such as storing energy to meet periods of peak demand and improving overall reliability.
Export Cable Corridor (ECC)	The specific corridor of seabed (seaward of Mean High Water Springs (MHWS)) and land (landward of MHWS) from the Hornsea Project Four array area to the Creyke Beck National Grid substation, within which the export cables will be located.
Global Warming Potential (GWP)	Global Warming Potential of a greenhouse gas (GHG) is a measure of how much heat is trapped by a certain amount of gas in the atmosphere relative to carbon dioxide.
Greenhouse gas (GHG)	A greenhouse gas is a gas that traps heat in the atmosphere and causes the greenhouse effect.
Hornsea Project Four Offshore Wind Farm	The term covers all elements of the project (i.e. both the offshore and onshore). Hornsea Four infrastructure will include offshore generating stations (wind turbines), electrical export cables to landfall, and connection to the electricity transmission network. Hereafter referred to as Hornsea Four.
Landfall	The generic term applied to the entire landfall area between Mean Low Water Spring (MLWS) tide and the Transition Joint Bay (TJB) inclusive of all construction works, including the offshore and onshore ECC, intertidal working area and landfall compound. Where the offshore cables come ashore east of Fraisthorpe.
Offshore substation platform	A fixed structure located within the wind farm area, containing electrical equipment to aggregate the power from the wind turbine generators and convert it into a more suitable form for export to shore.
Onshore substation (OnSS)	Comprises a compound containing the electrical components for transforming the power supplied from Hornsea Project Four to 400 kV and to adjust the power quality and power factor, as required to meet the UK Grid Code for supply to the National Grid. If a HVDC system is used the OnSS will also house equipment to convert the power from HVDC to HVAC.

Orsted Hornsea Project Four Ltd.	The Applicant for the proposed Hornsea Project Four Offshore Wind Farm Development Consent Order (DCO)
Transition Joint Bay (TJBs)	TJBs are pits dug and lined with concrete, in which the jointing of the offshore and onshore export cables takes place.
Trenchless Techniques	Also referred to as trenchless crossing techniques or trenchless methods. These techniques include Horizontal Directional Drilling (HDD), thrust boring, auger boring, and pipe ramming, which allow ducts to be installed under an obstruction without breaking open the ground and digging a trench

Acronyms

Term	Definition
BEIS	Department for Business, Energy and Industrial Strategy
CCGT	Combined Cycle Gas Turbine
CH_4	Methane
CO_2	Carbon dioxide
CO_2e	Carbon dioxide Equivalent
$CO_2e.kWh^{-1}$	Carbon dioxide equivalent per kilowatt-hour
DCO	Development Consent Order
DfT	Department for Transport
EBI	Energy Balancing Infrastructure
ECC	Export Cable Corridor
ExA	Examining Authority
GBS	Gravity based structure
GHG	Greenhouse gas
GW	Gigawatt
GWP	Global Warming Potential
HDD	Horizontal Directional Drilling
HFC	Hydrofluorocarbon
HGV	Heavy Goods Vehicle
ICE	Inventory of Carbon and Energy
IPCC	Intergovernmental Panel on Climate Change
HLV	Heavy lifting vessel
km	Kilometre
HTV	Heavy transport vessel
kW	Kilowatt
kWh	Kilowatt-hour
kV	kilovolt
LCA	Life Cycle Analysis

MGO	Marine gas oil
MW	Megawatts
N_2O	Nitrous oxide
NGET	National Grid Electricity Transmission
NF_3	Nitrogen trifluoride
NRMM	Non-Road Mobile Machinery
O&M	Operation and Maintenance
OnSS	Onshore Substation
OS	Offshore Substation Platform
PRC	Perfluorocarbon
SBJ	Suction bucket jacket
SF_6	Sulphur hexafluoride
SoS	Secretary of State
TBJ	Transition Joint Bay
UK	United Kingdom
WTG	Wind Turbine Generator

1 Introduction

1.1.1.1 Orsted Hornsea Project Four Limited (the 'Applicant') is proposing to develop Hornsea Project Four Offshore Wind Farm (hereafter 'Hornsea Four'). Hornsea Four will be located approximately 69 km offshore the East Riding of Yorkshire in the Southern North Sea and will be the fourth project to be developed in the former Hornsea Zone. Hornsea Four will include both offshore and onshore infrastructure including an offshore generating station (wind farm), export cables to the landfall, and on to an onshore substation (OnSS) with energy balancing infrastructure (EBI), and connection to the electricity transmission network.

1.1.1.2 This report represents an assessment of the greenhouse gas (GHG) footprint of activities associated with Hornsea Four.

1.1.1.3 This assessment contains a quantified assessment of GHG emissions over the lifetime of Hornsea Four and considers both the onshore and offshore components of the development and encompasses the construction, operation & maintenance (O&M) and decommissioning phases.

1.1.1.4 Within these phases, the GHG footprint for Hornsea Four accounts for five main source groups, which are listed below:

- Embodied carbon within materials used for the onshore and offshore components of Hornsea Four;
- Emissions associated with the movement of marine vessels;
- Emissions from the movement of helicopters;
- Emissions associated with the movement of road vehicles; and
- Emissions from the use of plant and equipment.

1.1.1.5 GHG calculations were derived using available information at the time of the assessment, which included activities associated with the source groups listed above.

1.1.1.6 During 2020, 59% of electricity consumed in the UK was generated by 'low carbon' sources such as nuclear, solar, biomass and wind. Approximately 38% of the generation share was from fossil fuels, which primarily comprised gas. While energy demands fell in 2020 to levels not seen since the 1950s due to the Covid-19 pandemic, renewable generation (as a percentage of generation) continued to grow and reached a record 43% in 2020, an increase from 37% in 2019 and outpacing annual fossil fuel generation for the first time. Between 2016 and 2020, UK wind generation more than doubled, and in 2020, 24.2% of electricity consumed was produced by wind (BEIS 2021a).

1.1.1.7 In 2021, the installed generating capacity in the UK of onshore and offshore wind farms was 24.74 gigawatts (GW), consisting of 14.2 GW and 10.5 GW of onshore and offshore capacity respectively (RenewableUK, 2021). The total capacity of Hornsea Four is currently anticipated to be in the order of 2.6 GW, based on current knowledge relating to technology and grid capacity. Therefore, Hornsea Four will contribute significantly to the decarbonisation of the UK energy supply.

1.2 Purpose of document

1.2.1.1 The purpose of the GHG footprint assessment was to quantify emissions associated with Hornsea Four for both the onshore and offshore components. Existing literature was used to place the outcomes of the GHG footprint in the context of the wider offshore wind industry, and to provide a benchmark to verify the outcomes of the assessment.

1.2.1.2 Following submission of the Hornsea Four Development Consent Order (DCO), the first round of questions received from the Examining Authority (ExA) included the following (see question BGC.1.15):

1.2.1.3 "Carbon Impact Assessment: During consultation for the redetermination of the Norfolk Vanguard project, the Secretary of State (SoS) highlighted the desirability of a carbon footprint and impact assessment that considered embedded carbon and greenhouse gases from the extraction, refinement and manufacture of elements of the project, along with the emissions from the construction (including trenching and excavation of arable land and loss of greenhouse gas absorption capacity from farming, plants and trees), operation, maintenance and decommissioning. Could the Applicant signpost any assessment work of this nature that has been undertaken and does the Applicant intend to provide anything further in this respect?"

1.2.1.4 In response to this question, the Applicant has undertaken a GHG footprint assessment (this document) which has considered embedded carbon and GHGs regarding extraction, refinement and manufacture of elements of Hornsea Four, as well as emissions from construction, operation, maintenance and decommissioning.

1.2.1.5 Hornsea Four will result in the permanent loss of 18.9 ha of land at the OnSS, as set out in Paragraph 6.11.1.6 of **A3.6 Land Use and Agriculture (APP-030)**, and minimal permanent loss of above ground vegetation. Therefore, GHG emissions associated with the loss of GHG absorption capacity is likely to be negligible and was not considered further in the assessment.

1.2.2 Project Description

1.2.2.1 Details of the activities and infrastructure associated with Hornsea Four are fully set out in **A1.4 Project Description (REP01-004)**. In summary, the onshore elements of Hornsea Four will comprise:

- **Landfall** – including transition joint bays connecting the offshore export cable corridor (ECC) and onshore ECC, one temporary landfall compound and temporary access tracks;
- **Onshore ECC –** including the onshore export cables, eight temporary logistics compounds, joint bays and link boxes, and temporary access tracks;
- **OnSS and EBI** – including the temporary working area, temporary and permanent access tracks, the permanent working area (inclusive of the OnSS, EBI and associated landscaping and attenuation feature); and,
- **400 kV National Grid Electricity Transmission (NGET) connection** area – the area within which a 400 kV section of the onshore ECC will connect to the existing NGET substation at Creyke Beck.

1.2.3 Context

1.2.3.1 The construction, O&M and decommissioning of wind farm projects entail the generation of GHG emissions, both from the standpoint of:

- **Embedded carbon and GHGs** – the emissions caused by the extraction and refinement of raw materials and their manufacture into the commodities and products that make up the components of the wind turbine generators (WTGs) and their associated physical infrastructure; and
- **Carbon and other GHG emissions** arising from the combustion of fuels and energy used in constructing, operating and maintaining Hornsea Four components over its lifetime and in decommissioning.

1.2.3.2 There are inherent uncertainties associated with carrying out GHG footprint assessments for offshore wind power projects, although the approach to determine emissions from individual source groups (see **Section 3.2**) is well defined.

1.2.3.3 A report published by the University of Edinburgh in 2015 (Thomson & Harrison 2015) examined the lifecycle costs and GHG emissions associated with offshore wind energy projects, comparing data gleaned from the analysis of some 18 studies carried out over the period 2009 to 2013. This report provided useful context for the Hornsea Four GHG assessment, and benchmark figures which were used to verify the outcomes of the assessment.

1.2.3.4 **Table 1** provides a summary of the percentage of total GHG emissions associated with the different phases of an offshore wind farm development, as provided within the report (Thomson & Harrison 2015).

Table 1: Summary of Offshore Wind Farm GHG Emissions (Thomson & Harris 2015).

Phase	% of Total GHG Emissions
Manufacture and Installation	78.4
O&M	20.4
Decommissioning	1.2

1.2.3.5 The report highlighted that the greatest proportion of emissions are associated with the manufacture and installation of the wind farm components. Decommissioning accounted for the smallest proportion, only 1.2%, of total life cycle GHG emissions. A more detailed breakdown of emissions is given in the Thomson & Harris (2015) report for an offshore windfarm with steel foundations. For completeness, this information has been reproduced in **Table 2**.

Table 2: Further Detailed Breakdown of GHG Emissions (Thomson & Harris 2015).

Component or Phase	% of Total GHG Emissions
Foundations	34.7
Turbines	23.8
Cables & transformers	19.8
Maintenance shipping	14.3
Spare parts	3.7
Maintenance helicopter	2.4
Dismantling and disposal	1.2

1.2.3.6 Of the high-level project phases listed in **Table 1** GHG emissions associated with foundation fabrication and installation accounted for the largest proportion of emissions (34.7%), followed by manufacture and installation of the turbines (23.8%) and the cables and transformers (19.8%). GHG emissions from shipping movements during maintenance operations over the operational lifetime of the wind farm contributed 14.3%[1].

1.2.3.7 The GHG emissions associated with shipping movements may appear to be unexpectedly high, but the vessel movements contribution is associated with a 20-year operational lifespan of the wind farms considered in the studies. Emissions derived from spare parts (3.7%), helicopter movements (2.4%) and dismantling and disposal (1.2%) are all small, in comparison.

1.2.3.8 Additional analysis of the data extracted from the 18 technical studies expressed the GHG emissions as grammes (g) of CO_2e per kilowatt-hour (kWh) of electricity generated. These were found to vary quite widely, between approximately 5 and 33 g $CO_2e.kWh^{-1}$. There was no clear relationship between the metrics and either turbine rating (in MW) or capacity factor.

1.2.3.9 A further study in 2012 (Dolan & Heath 2012), amassed the results of over 200 studies of carbon emissions from wind power and attempted to "*harmonise*" the results to use only the most robust and reliable data and to align methodological inconsistences. The harmonised results of this study revealed that the range in GHG emissions per kWh of electricity generated varied between approximately 7 and 23 g $CO_2e.kWh^{-1}$, with a mean value of around 12 g $CO_2e.kWh^{-1}$.

1.2.3.10 To place these metrics into context, comparable values for electricity generation by gas are around 380 g $CO_2e.kWh^{-1}$ (31 times that of offshore wind) and, for coal, approximately 985 g $CO_2e.kWh^{-1}$ (82.1 times that of offshore wind) (BEIS, 2020).

1.2.3.11 Although robust and fit for purpose, this report should not be taken to be a comprehensive, detailed Life Cycle Analysis (LCA) of Hornsea Four. The reason that this report does not take the form of a detailed LCA is, because it is not possible to fully define the supply chain for the project and undertake the relevant detailed assessments at this stage. Therefore, assumptions and simplifications to the methodology were made in certain areas and a

[1] Shipping GHG emissions associated with installation of the wind farm components are included within the first three categories in **Table 2**.

precautionary approach was adopted for the assessment to allow for this. These assumptions and simplifications are referred to at the relevant point in **Section 3.3**.

2 Legislative background

2.1.1.1 In the Intergovernmental Panel on Climate Change (IPCC)'s most recent synthesis Report (IPCC 2014[2]) on the science of climate change, it was reported that the IPCC *"is now 95 percent certain that humans are the main cause of current global warming"* (IPCC, 2014), and that the observed temperature rises over this period and those predicted in the future are anticipated to give rise to deleterious effects across the globe arising from temperature rises, changes to the global water cycle, changes to ocean temperatures, changes to sea level and changes to the global carbon cycle.

2.1.1.2 On 12 December 2015, the UK along with 195 other parties signed the 'Paris Agreement', a legally binding international treaty on climate change committing all parties to the goal of limiting global warming to well below 2 degrees Celsius, preferably to 1.5 degrees Celsius, compared to pre-industrial levels. The Agreement requires all parties to submit plans to reduce their emission (along with other climate action) every 5-years, starting in 2020.

2.1.1.3 In December 2020, the UK set a Sixth Carbon Budget, recommending a reduction in UK GHG emissions of 78% by 2035 relative to a 1990 baseline (a 63% reduction from 2019) (CCC 2020). This target which has already been enshrined in UK law has been set in line with the UK commitments in relation to the Paris Agreement and with the goal of achieving a target of reaching net zero GHG emissions by 2050.

2.1.1.4 As part of this budget, the role of the offshore wind sector and the construction industry are both the focus of action to contribute to meeting these targets.

3 Methodology

3.1 Approach

3.1.1.1 In this assessment the term 'GHG' or 'carbon' encompasses carbon dioxide (CO_2) and the six other gases as referenced in the Kyoto Protocol. These are methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PRCs), sulphur hexafluoride (SF_6) and nitrogen trifluoride (NF_3)[3]. Where practicable, the results in this assessment are expressed in carbon dioxide equivalent (CO_2e), which recognises that different gases have notably different global warming potentials (GWP)[4].

3.1.1.2 Emissions were quantified for the construction, operational and decommissioning phases to determine an overall GHG footprint for Hornsea Four. GHG emissions per kWh of energy generated by Hornsea Four were also calculated.

3.1.1.3 The system boundary of the GHG footprint includes material extraction and manufacturing, transport and installation, O&M and end of life and decommissioning. A schematic diagram of the Hornsea Four system boundary is provided in **Figure 1**.

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[2] Note the IPCC AR6 synthesis report is due for publication in September 2022
[3] NF_3 was incorporated in the second Kyoto Protocol compliance period in 2012.
[4] Global Warming Potential (GWP) of a GHG is a measure of how much heat is trapped by a certain amount of gas in the atmosphere relative to carbon dioxide.

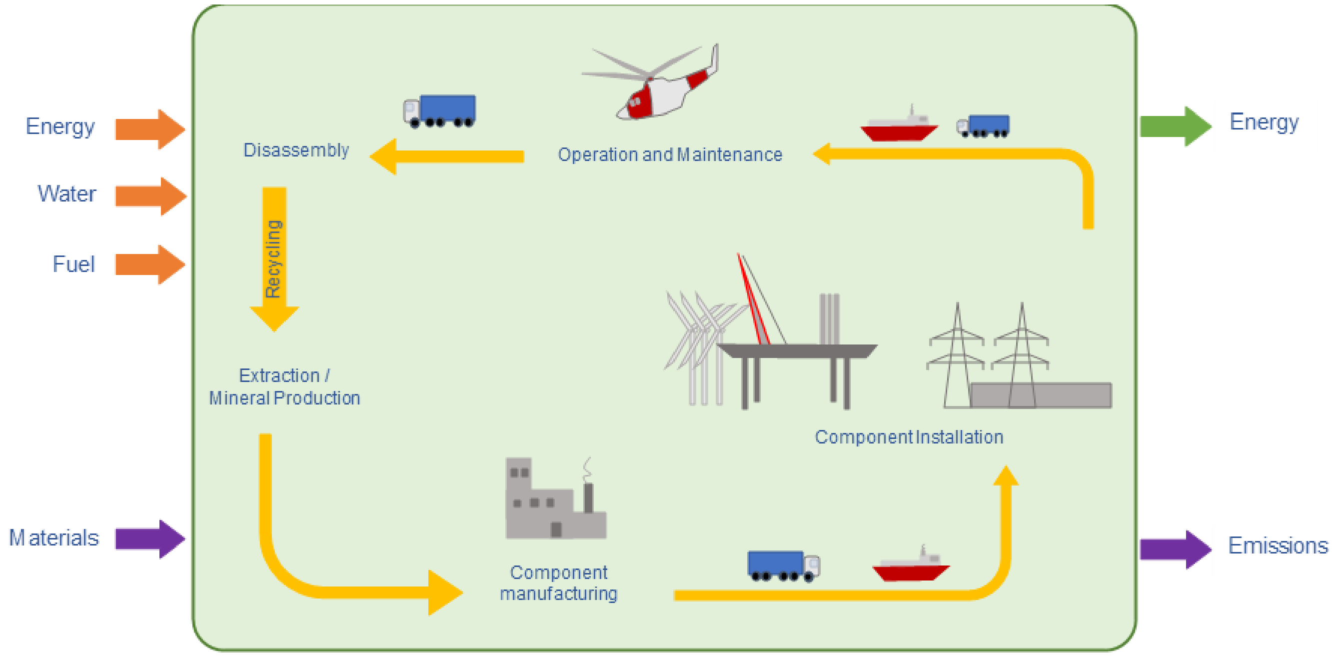

Figure 1: System Boundary for Hornsea Four GHG Assessment.

3.2 Emission Calculations

1. The emission sources for Hornsea Four have been categorised into five main source groups, as detailed in Table 3.

Table 3: Emission Source Groups Considered in the Assessment.

Source ID	Source Name	Definition	Project Sources
1	Embodied emissions in materials (offshore and onshore)	Embodied emissions within materials comprise GHGs released throughout the supply chain, and includes the extraction of materials from the ground, transport, manufacturing, assembly and its end-of-life profile.	Embodied emissions were quantified for the main construction materials to be used for the onshore and offshore components of Hornsea Four. The components that were considered included the main infrastructure associated with Hornsea Four, such as foundations, WTGs, cables (onshore and offshore), landfall and the onshore project substation. The requirement for spare (or replacement) parts during operation is not known at this stage, therefore the likely composition of emissions in terms of the overall footprint of Hornsea Four was obtained from existing literature (Thompson & Harrison 2015).
2	Marine vessels (offshore)	GHG emissions are released in exhaust gases from the combustion of fossil fuels on marine vessels.	Emissions were calculated associated with the movement of marine vessels for the offshore component of Hornsea Four. Vessels associated with installation of foundations, wind turbines and cables, as well as supply and support, accommodation and commissioning vessels were also quantified.

			Marine vessel movements during the O&M phase were also quantified.
3	Helicopter (offshore)	Emissions are released in exhaust gases from the combustion of fuel in helicopters	Emissions were calculated form the movement of helicopters from an onshore port during construction and the O&M phase.
4	Road traffic vehicles (onshore)	Emissions associated with the movement of road vehicles.	Emissions were calculated associated with the movement of Heavy Goods Vehicles (HGVs) during construction, and staff travel during construction and operation.
5	Plant and equipment (onshore)	Emissions are released from Non-Road Mobile Machinery (NRMM) as a result of fuel combustion.	Emissions were calculated from the use of NRMM during construction of the onshore component of Hornsea Four from data available at the time of assessment.

3.2.1.1 Activities that will take place during the decommissioning phase are unknown at this stage. Emissions from decommissioning were therefore derived from previous studies (Thomson & Harrison 2015), which quantified them to be approximately 1.2% of the GHG footprint of an offshore windfarm.

3.2.1.2 The approach to quantifying GHG emissions for each of the source groups detailed in **Table 3** are provided in the sections below. Further details with respect to the origin of the values used within the GHG assessment are provided in **Appendix A**.

3.2.2 Embodied emissions in materials

3.2.2.1 Emissions of 'cradle to (factory) gate', a term which includes the extraction, manufacture and production of materials to the point at which they leave the factory gate of the final processing location, were calculated for Hornsea Four. GHG emissions were derived from quantities or volumes of known materials that will be used in construction, including the following infrastructure:

- The key offshore components comprise:
  - WTG's (tower, nacelle, hub and blades);
  - Offshore substation platform (OSS) and offshore booster/converter stations;
  - Foundation structures for the WTG's (i.e. monopiles and transition pieces, suction bucket jacket (SBJ) and gravity based structures (GBSs)), pile-structure and structure-seabed grouting, scour protection, and the OSS and offshore booster/converter stations (i.e. jacket and piles); and
  - array, offshore interconnector and offshore export cables and cable rock protection.
- The key onshore components comprise:
  - Landfall and the associated transition joint bay and logistic compound;
  - Onshore ECC installed underground from landfall to the OnSS;
  - OnSS and EBI and onward 400 kV connection to the existing NGET substation at Creyke Beck;
  - Trenchless crossings (e.g. Horizontal Directional Drilling (HDD's));
  - Haul road; and
  - HDD and logistic compounds.

3.2.2.2 To provide a precautionary assessment, it was assumed that there will be no reduction in the emissions intensity during abstraction and manufacturing of materials up until and during the construction phase of Hornsea Four. The earliest pre-construction could commence under any scenario is anticipated to be 2024, and the maximum total construction duration (including both onshore and offshore) is five years and one month (i.e. 61 months). The quantities of each type of construction material to be used on site were obtained from the Applicant's technical team, and the relevant emission factors sourced from the Inventory of Carbon and Energy (ICE) database (Jones & Hammond 2019) where possible. Alternative sources for emission factors were used for more specific components to offshore wind farms (i.e. cables), and are detailed in **Appendix A**.

3.2.2.3 Precautionary assumptions were adopted with respect to material quantities to be used for each component of Hornsea Four, which include contingency allowing for the worst-case scenario of the maximum design scenario to be accounted for.

3.2.2.4 There are many possible foundation types currently available to support offshore wind turbines and/or offshore platforms. Based on the current best estimates of foundations to be used for Hornsea Four, emissions were quantified for monopiles, SBJ's and GBS foundation types in the carbon footprint assessment. It has been estimated that of the 180 WTG, 87 (48%), 45 (25%) and 48 (27%) would be monopiles, SBJs and GBSs respectively.

3.2.2.5 The emission factors from the ICE database are 'cradle-to-factory' and therefore do not include the transportation of materials to site. Emissions associated with the movement of materials to the site were quantified from the road traffic vehicle and marine vessel source groups, detailed in **Sections 3.2.3** and **3.2.4** respectively. The road traffic vehicle source group also included emissions associated with the removal of excavated materials from the site.

3.2.2.6 Hornsea Four will incorporate EBI to provide valuable services to the whole energy system, such as importing, storing and exporting energy, or converting to other energy sources to meet the grid needs, improve stability and reliability and support the UK's transition to Net Zero. The provision of EBI may result in the release of GHG emissions, particularly through the construction of any batteries that are used. The amount of GHG's associated with the use of storage and batteries is dependent on a number of factors, including the type of battery, the manufacturing process, battery capacity and the number of charge cycles it is capable of.

3.2.2.7 The behaviour of both the electricity grid and electricity markets are dynamic and will change between now and the timing of the final design of the EBI. This means that the performance needs and therefore the dimensioning of the EBI will not be fully understood until closer to the final design of the infrastructure.

3.2.2.8 In addition, EBI technology such as battery energy storage is advancing and improving rapidly thanks to many parameters such as the mass uptake of electric vehicles. Therefore, GHG emissions from with the provision of EBI associated with Hornsea Four were not calculated at this stage.

3.2.3 Marine Vessels

3.2.3.1 Marine vessels will be used to bring materials and components to the Hornsea Four offshore array area, install infrastructure (foundations, WTG, OSS, booster/converter stations and offshore array/interconnector/export cables), provide crew accommodation and support during construction, commissioning and O&M.

3.2.3.2 Topside infrastructure will be installed by crane and heavy lifting vessels (HLVs), which will travel to the site via heavy transport vessels (HTVs), likely from ports in Europe. GHG emissions associated with the transport of vessels to the site, and during the installation process were quantified.

3.2.3.3 Marine vessels will also be used to transport scour protection material (i.e. quarried rock), which for the purposes of the GHG is assumed to be sourced from Norway as a worst case. GHG emissions associated with these deliveries were also quantified.

3.2.3.4 For some construction processes, the vessel likely to be used during installation was already known, therefore fuel consumption figures were calculated by multiplying the engine size of the vessels by activity hours on site (accounting for average engine load factors). Where the vessel to be used was unknown, vessel types and engine sizes were obtained from those used on previous Hornsea offshore wind farm projects, to determine fuel consumption.

3.2.3.5 Marine vessel information was provided by the Applicant's technical team to derive estimated fuel consumption during construction and operation. Emission factors for marine gas oil (MGO), in kg $CO_2e.kWh^{-1}$ were obtained from the Department for Business, Energy and Industrial Strategy (BEIS) (BEIS 2021b). The shipping sector is expected to decarbonise over the lifespan of the project, although projections for the speed and the extent that this will take place are difficult to predict. It was therefore assumed that marine vessels continued to use MGO during the construction and O&M phases of Hornsea Four. This approach is considered to be conservative and may result in an overestimation of emissions particularly with respect to the O&M phase.

3.2.3.6 The installation vessels for offshore wind projects are specialised for the implementation of components such as wind turbines and substations. Such vessels include crane lifting equipment and other plant and machinery that are required during the installation process. It was assumed in the assessment that this specialised equipment is also powered by MGO.

3.2.3.7 Some elements of the data used to calculate GHG emissions from marine vessels are confidential at this stage due to commercial aspects, therefore a detailed breakdown of information used to derive GHG emissions from this source cannot be reproduced in this report.

3.2.4 Helicopters

3.2.4.1 Helicopter movements associated with the construction and O&M phases of Hornsea Four will result in the release of GHG emissions. The volume of GHG emissions from helicopters was calculated by determining the expected fuel consumption using trip data provided by the Applicant's technical team.

3.2.4.2 The total distance travelled by helicopters was determined by multiplying the number of trips by the average trip distance. It was assumed that three types of helicopter would be used, AW139, AW169 and AW189. The average cruise speed (km/hr) and fuel consumption (kg/hr) data for each of these helicopters was obtained from manufacturers specifications to estimate fuel consumption.

3.2.4.3 Emission factors for aviation turbine fuel (or jet fuel), in kg $CO_2e.T^{-1}$ fuel were obtained from the Department for Business, Energy and Industrial Strategy (BEIS) (BEIS 2021b).

3.2.5 Road Traffic Vehicles

3.2.5.1 Road traffic vehicle movements associated with the construction and O&M phases of Hornsea Four will result in the release of GHG emissions. GHG emissions were calculated from total kilometres travelled by HGVs and staff transport to and from the construction sites, and during the O&M phase.

3.2.5.2 Anticipated changes to the fleet make up (in terms of fuel and Euro Standards) were incorporated into the earliest year of construction (2024) and these were used for each of the future years of the assessment for staff travel (assumed to be private cars, which is a precautionary assumption as there are likely to be organised transport options and measures to reduce staff travel journeys). The forecasted change in the fleet composition of diesel, petrol and electric cars was obtained from the Department for Transport (DfT) WebTAG data v1.17 (DfT 2021). In the absence of suitable empirical data, it was assumed that the fleet composition of HGVs did not change over the temporal scope of the assessment to provide a precautionary approach.

3.2.5.3 Emission factors for each vehicle type considered in the assessment were obtained from BEIS (2021b), in kg CO_2e per km travelled. To provide a precautionary assessment, it was assumed that there were no fuel efficiency improvements or reduction in emissions over the project period for each mode of transport in the assessment.

3.2.5.4 Distances travelled for all scenarios were calculated for HGV movements and staff travel according to the following methodology:

- **HGV movements**:
  - Total project HGV vehicle movements were collated from **A3.7 Traffic and Transport (APP-031)**;
  - The methodology to calculate HGV movements is presented in **A3.7 Traffic and Transport (APP-031)** and **A6.7.1 Traffic and Transport Technical Report (APP-125)**, which assumes that as a worst case, all vehicles will have origin destination of the A63, to the south of Hull; and
  - The total HGV movements were multiplied by the estimated distances per trip, resulting in a value of the total HGV distance travelled in km.
- **Staff travel**:
  - Total employee vehicle movements were collated from **A3.7 Traffic and Transport (APP-031)**; and
  - To determine the distances associated with staff travel (i.e. cars), assumptions were obtained from the socio-economic assessment in relation to likely employee distribution. It was assumed that 70% of the workforce would be drawn from the local area (known as 'resident' labour) and the remaining 30% of the workforce would be sourced from a distance beyond a reasonable daily commute (referred to as 'in-migrant' labour). As a worst case, it was assumed that no car-sharing or use of sustainable transport (i.e. each employee trip generates one car trip) took place.

3.2.5.5 During the O&M phase of Hornsea Four, traffic movements would be largely preventative and corrective, with remote monitoring of the onshore ECC and OnSS. It was therefore assumed that there would be five 'local' (i.e. Hull area) employee trips per week during the 35-year lifespan of the operational phase of Hornsea Four. This visit was assumed to be a 16 mile round-trip, i.e. 8 miles each way, which is similar to the UK average and amounted to approximately 4,160 miles per annum.

3.2.6 Plant and Equipment

3.2.6.1 Fuel consumption associated with the operation of NRMM for the onshore components of Hornsea Four were calculated based on the estimated use of each item of plant and equipment, with representative engine sizes derived from manufacturer specifications. Construction plant and equipment, along with their anticipated duration and programmme, were provided by the Applicant's technical team, which includes earth moving equipment, cranes and specialist equipment.

3.2.6.2 The anticipated fuel demand over the duration of construction was calculated and the emission factor for gas oil consumption was obtained from BEIS (2021b) to derive GHG emissions.

3.2.6.3 The following assumptions were adopted in the assessment:

- Plant and equipment would operate throughout the core working hours for the project (66 hours). An on-time factor was applied for each plant and equipment;
- Construction plant and equipment were all assumed to use diesel to provide a conservative assessment; and
- Engine sizes for plant and equipment were obtained for NRMM typically required during construction activities, and from manufacturer specifications. It was assumed that engines operated at a load factor of 75%.

3.3 Limitations

3.3.1.1 The key limitations of the assessment, and how they have been addressed, are listed in Table 4.

Table 4: Key Limitations of the GHG Assessment.

ID	Limitation	Action Taken
1	Quantities for all materials to be used during construction were not available at the time of the assessment.	Quantities of the main and most GHG intensive materials were included in the assessment. Furthermore, precautionary assumptions were adopted for quantities of known materials (i.e. using the maximum quantity), particularly for quantities of concrete and scour protection.
2	Lack of emission factors for future year activities, such as fuel consumption and material extraction.	The most recent available emissions factors were used in the assessment to provide a precautionary assessment.
3	Expected operational requirements of construction plant and equipment for the onshore components were not known at the time of the assessment.	An on-time correction factor was applied to all listed plant and equipment for construction of each component, which may not be applicable for all NRMM considered in the assessment.

4	Specific nature and composition of some materials, such as the type of concrete or steel to be used, was unknown which may affect the carbon intensity of the material.	If there was variation across different compositions of the same material, the 'General' option was chosen, if available, or the median value if not.
5	Duration O&M marine vessels remain on site	The duration O&M marine vessels would visit the site during O&M activities is not known, therefore it was assumed to be two weeks per visit per O&M vessel over the 35-year O&M period.

4 Results

4.1.1.1 GHG emissions associated with the construction phase are presented in **Table 5**.

Table 5: Construction Phase GHG Emissions by Source.

Source Group	GHG Emissions (Tonnes CO_2e)	Percentage of Construction GHG Footprint
Embodied Carbon Offshore	2,917,470	81.6%
Embodied Carbon Onshore	158,679	4.4%
Vessels	504,429	14.1%
Helicopter	1,881	0.1%
Construction Road Traffic	3,757	0.1%
Construction Plant and Equipment	2,168	0.1%
Total for Construction	**3,588,384**	-

4.1.1.2 The highest source of emissions during the construction phase is anticipated to be associated with embodied carbon in the offshore components of Hornsea Four. Embodied carbon in materials used for both the onshore and offshore components are predicted to contribute 86% of the total emissions contribution during construction.

4.1.1.3 GHG emissions released during the 35 year O&M phase of Hornsea Four are presented in **Table 6**.

Table 6: O&M Phase GHG Emissions by Source.

Source Group	GHG Emissions (Tonnes CO_2e)	Percentage of O&M GHG Footprint
Vessels	3,844,802	93.0%
Helicopter	143,603	3.5%
Road Traffic	49	0.0%
Spare Parts	147,573	3.6%
Total for O&M	**4,136,026**	-

4.1.1.4 Vessels were predicted to be the largest source of emissions to the O&M phase footprint, contributing approximately 93% to the total footprint. This is likely to be an overestimation of emissions from vessels during this phase as the shipping sector is likely to decarbonise over this period.

4.1.1.5 Predicted GHG emissions from each phase of Hornsea Four are detailed in **Table 7.**

Table 7: GHG Emissions Associated with each Phase of Hornsea Four.

Source Group	GHG Emissions (Tonnes CO_2e)	Percentage of Carbon Footprint
Construction	3,588,384	45.6%
O&M (35-year period)	4,136,026	52.6%
Decommissioning	139,039	1.8%
Total	**7,863,450**	-

4.1.1.6 The results presented in **Table 7** highlights those emissions associated with the 35 year O&M phase forms the largest component of the Hornsea Four GHG footprint. Annual emissions during the O&M phase are predicted to be 118,172 tonnes CO_2e per year.

4.1.1.7 As detailed in **Table 6**, the largest source of emissions during the O&M phase is predicted to be from vessel movements, which is likely to be a conservative figure due to the likely decarbonisation of the shipping sector throughout the lifespan of Hornsea Four.

5 Discussion

5.1.1.1 The results presented in **Section 4** show that the total GHG footprint for Hornsea Four is 7,863,450 tonnes CO_2e over the project lifetime. This includes a duration of the construction phase, an operational lifetime of 35 years and decommissioning of Hornsea Four.

5.1.1.2 The GHG intensity per unit of electricity produced by Hornsea Four was determined by dividing the predicted quantity of emissions by the anticipated energy produced over its lifespan.

5.1.1.3 The approach to estimating the amount of energy produced by Hornsea Four was derived from the approach advocated by RenewableUK (2022), where the installed capacity (assumed to be 2.6 GW) was multiplied by the hours in the year and by the appropriate average load or capacity factor for Hornsea Four. For new build offshore projects, BEIS advises that the load factor is 63.1% (BEIS 2021c).

5.1.1.4 Using this approach, the annual energy generated by Hornsea Four is estimated to be approximately 14,372 GWh per annum. Energy generated by Hornsea Four over the 35-year lifespan of the project is estimated to be 503,008 GWh.

5.1.1.5 The GHG intensity of the electricity produced by Hornsea Four is therefore 15.6 g $CO_2e.kWh^{-1}$. When compared with other offshore windfarm life cycle studies (Thomson & Harrison 2015; Dolan & Heath 2012), the GHG intensity of Hornsea Four is in the mid-range for offshore wind projects. As noted in **Section 3**, a number of conservative assumptions were adopted in the assessment, therefore the GHG footprint of Hornsea Four, particularly during the O&M phase is likely to be an overestimation.

5.1.1.6 To estimate the 'GHG payback' period of Hornsea Four, it was assumed that electricity produced by combined cycle gas turbine (CCGT) is displaced (0.380 kg/kWh), as this is the most common form of new plant in the UK in terms of fossil fuel combustion (BEIS 2021a). This is a conventional and accepted approach in GHG accounting. An alternative approach to determining the 'GHG payback' of Hornsea Four would be to use the future electricity emission factors of the UK grid, for which projections are available from BEIS (BEIS 2021a). However, these projections will account for renewable energy projects such as Hornsea Four becoming operational and decarbonising the UK electricity grid. Therefore, the use of the future projection of the UK grid is not considered to be a reasonable approach when determining the 'GHG payback' of a renewable energy project.

5.1.1.7 The GHG payback of Hornsea Four, assuming that electricity produced by CCGT is displaced on the UK grid, is less than 1.5 years from the point when Hornsea Four becomes fully operational.

6 Summary

6.1.1.1 A GHG assessment was carried out for Hornsea Four to determine emissions that will arise from construction, O&M and decommissioning activities. The assessment considered emissions from the extraction and manufacture of materials, marine vessel, helicopter and road traffic movements, and the use of plant and equipment.

6.1.1.2 GHG emissions from construction, operation and decommissioning of Hornsea Four was predicted to be 7,863,450 tonnes of CO_2e. The largest GHG contribution to Hornsea Four is from marine vessels during the 35-year O&M phase of the project. Embodied emissions within materials forms the largest source during construction.

6.1.1.3 The GHG intensity of energy produced by Hornsea Four is anticipated to be 15.6 g $CO_2e.kWh^{-1}$. This is in the midrange of previous studies for offshore wind farms and therefore the carbon payback of emissions is likely to be less than 1.5 years from when Hornsea Four is connected and feeds into the UK grid.

7 References

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8 Appendices

8.1 Appendix A: GHG Emissions Calculation

8.1.1 A1 – Embodied Emissions in Materials

8.1.1.1 The emission factors used in the GHG assessment for embodied emissions in materials are presented in **Table A1**.

Table A1: Emission Factors for Embodied GHG in Materials

Material	Emission Factor ($kgCO_2e.kg^{-1}$, unless otherwise stated)	Source	Notes
Aggregate and Sand: Sand	0.00747	ICE Database V3.0 November 2019 (Jones & Hammond, 2019)	General UK, mixture of land won, marine, secondary and recycled, bulk, loose
Cement and mortar: Cement	0.83211		General (UK average)
Cement and mortar: Grout	0.62		Cement; Grout
Concrete	0.10336		General concrete
Steel (average)	2.47		Average of embodied CO_2e steel values provided in ICE Database
Stone/Gravel	0.079		Stone (general)
Plastic	3.31		N/A
Tarmac (per 100mm)	15.2		N/A
Aluminium	6.668717531		N/A
Copper	2.71		N/A
Iron cast	2.03224		N/A
Polypropylene	4.98		N/A
Epoxy	5.7		N/A
Balsa	0		N/A
Glass reinforced plastic (GRP) - Fibreglass (Fibreglass Proxy)	8.1		CO_2 only
Plastic: PVC Pipe	3.23		N/A
Copper (Cu) (cables)	2.71	Cableizer (2021)	N/A
XLPE (cables)	1.93		N/A
Semiconductor (cables – proxy) (paper)	1.49		N/A
PE sheath (cables)	2.54		N/A
Lead (Pb) (cables)	1.67		N/A
Armouring (cables)	1.46		N/A
PP yarn (cables)	3.69		CO_2 only
PE filler (cables)	2.54		N/A

8.1.2 A2 – Road Traffic Vehicles

8.1.2.1 The methodology used to derive total distance travelled by HGVs and employees in private cars is detailed in **Section 3.2.5**. The travel distances used in the assessment are presented in **Table A2**.

Table A2: Distances Travelled by HGVs and Employees during Construction.

Phase	HGVs (km Travelled)	Employees / Cars (km Travelled) –
Construction	3,457,661	5,331,796
O&M (per year)	0	4,160

8.1.2.2 The proportion of diesel, petrol and electric cars in the UK fleet for the first year of construction were obtained from the DfT (2021) to determine a representative emission factor associated with employee travel. The fleet composition used in the assessment, and emission factors associated with each vehicle type are provided in **Table A3**. Emission factors for each vehicle type were obtained from BEIS (2021b).

Table A3: Car Fleet Composition and Emission Factors used in the GHG Assessment.

Year	Fleet composition (DfT, 2021)			Vehicle emission factor (kg $CO_2e.km^{-1}$) (BEIS, 2021b)			Emission Factor Used in the Assessment (kg $CO_2e.km^{-1}$)
	Diesel	*Petrol*	*Electric*	*Diesel*	*Petrol*	*Electric*	
2024	53.1%	43.2%	3.7%	0.16843	0.17431	0.05477	0.167

8.1.2.3 It was assumed that all HGVs used on Hornsea Four were diesel powered. The emission factor for HGV movements (50% laden) was obtained from BEIS (2021b) and was 0.82851 kg $CO_2e.km^{-1}$.

8.1.3 A3 - Helicopter

8.1.3.1 Data used to determine GHG emissions from helicopter movements during the Construction and O&M phases of Hornsea Four are presented in **Table A4** and **Table A5** respectively.

Table A4: Data used to Determine Emissions from Helicopters During the Construction Phase.

Helicopter Type	Distance Travelled (km)	Cruise Speed	Hours	Helicopter Fuel Consumption (kg/hr)	Total Fuel Consumed (Tonnes)
AW139	150,827	306	493	430	212
AW169	150,827	300	503	270	136
AW189	150,827	273	553	440	244

Table A5: Data used to Determine Emissions from Helicopters During the O&M Phase.

Helicopter Type	Distance Travelled (km) – total O&M phase	Cruise Speed	Hours	Helicopter Fuel Consumption (kg/hr)	Total Fuel Consumed (Tonnes)
AW139	11,515,000	306	37,631	430	16,181
AW169	11,515,000	300	38,383	270	10,364
AW189	11,515,000	273	42,257	440	18,593

8.1.3.2 It was assumed that the helicopters used aviation turbine fuel. The emission factor for this fuel was obtained from BEIS (2021b) and was 3,181.4 kg CO_2e per tonne of fuel.

8.1.4 A3 – Plant and Equipment

8.1.4.1 Plant and equipment for the construction of Hornsea Four, as provided for the Applicant's technical team is provided below in **Table A6**. The information provided in **Table A6** represents the number of plant and equipment that could be present at any one time and is mainly focused on HDD works activities. The duration these plant and equipment were used was dependent on the construction programme of Hornsea Four.

8.1.4.2 Up to 60 passenger vehicles will be present for each of the work areas. At this stage in the Project, it is not known how far these vehicles will travel during construction. Therefore, it was assumed that each passenger vehicle would travel at an average of 10 km per day during construction. The emission factor for passenger vehicle movements was obtained from BEIS (2021b) and was 0.204 kg $CO_2e.km^{-1}$ (assumed to be a dual purpose 4 x 4 diesel vehicle).

Table A6: Plant and Equipment Requirements (at any one time) for each Component.

Name	No.	kW	On-Time Correction	Equipment
Drill rig (250 Tonne Rig)	4	390	75%	Drilling rigs (piling)
Drill Rig Hydraulic Power Unit	2	61.6	75%	Hydraulic Power Unit
Tractors	1	180	75%	John Deer
Mud Pump and Cleaner	2	562	75%	Well Service Mud Pump
Mud Shaker	1	2.94	75%	Solis Control
Generators	2	110	75%	Construction diesel generator
Hiab Loader Crane	1	129	75%	Loader Crane
Excavator	1	70	75%	JCB Rubber Tyred Excavator (Wheeled Excavator / Loader)
Long Reach Excavator	1	232	75%	CAT Long Reach
Vac Tanker	1	188	75%	Vacuum Tanker
Tele Handler	1	93	75%	Tele Handler
Pump	1	1.7	50%	Centrifugal Water Pump

8.1.4.3 For the purposes of the assessment, it was assumed that plant and equipment operated using gas oil as fuel, which has an emission factor of 0.273 kg $CO_2e.kWh^{-1}$. All plant were assumed to operate at an average load factor of 0.75 and a 66-hour working week