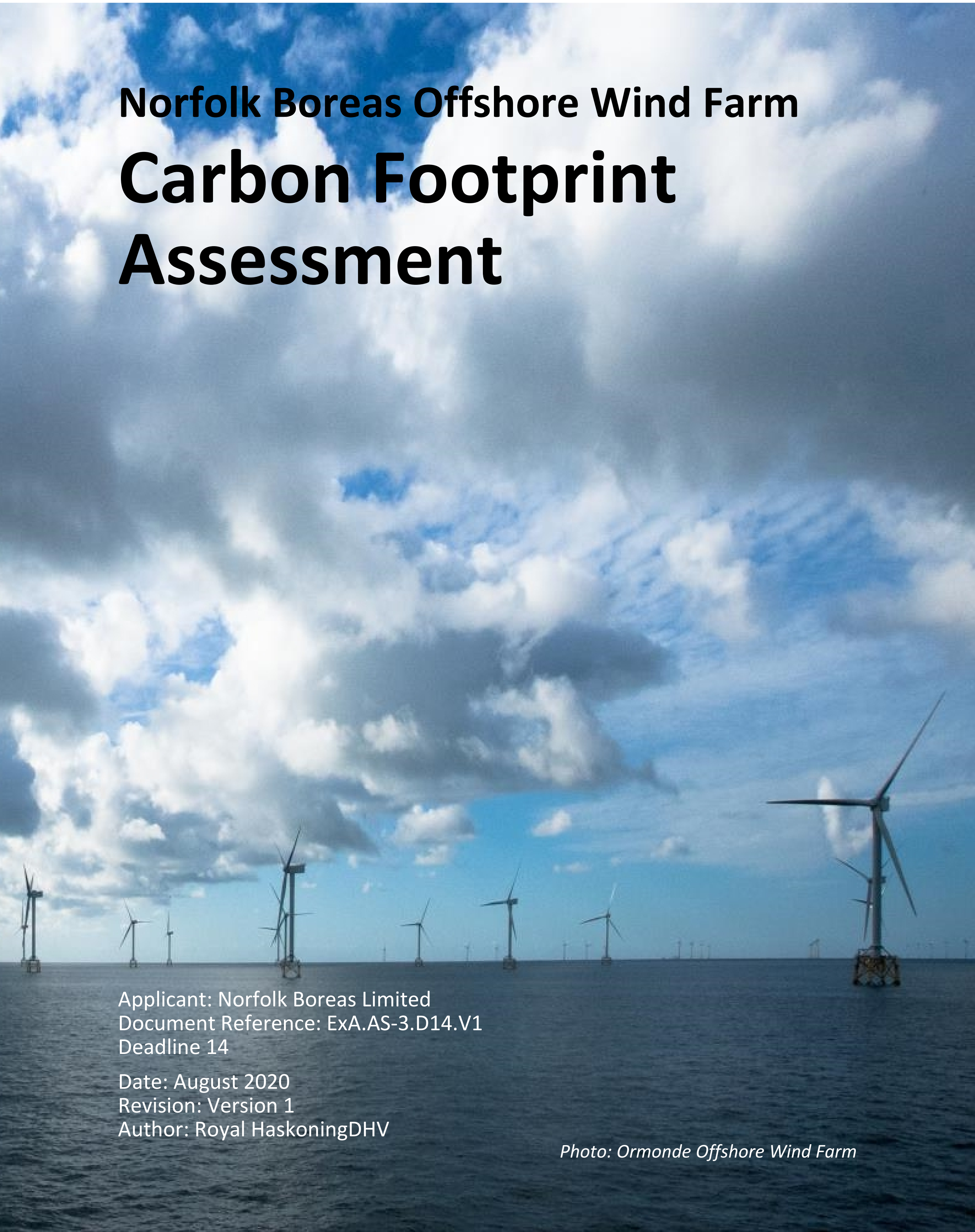
Norfolk Boreas Offshore Wind Farm

Carbon Footprint Assessment



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REPORT

Norfolk Boreas, Greenhouse Gas Footprint Assessment

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HASKONINGDHV UK LTD.

74/2 Commercial Quay
Commercial Street
Leith
Edinburgh
EH6 6LX
Industry & Buildings
VAT registration number: 792428892

+44 131 5550506 **T**
info.edinburgh@uk.rhdhv.com **E**
royalhaskoningdhv.com **W**

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Executive Summary

The Examining Authority (ExA) for the Norfolk Boreas offshore windfarm published a Rule 17 request for information on 20 July 2020, which included the following request of the Applicant (reference R17.1.31)

"In support of the 'zero net carbon' Climate Change Act 2008 (2050 Target Amended) Order 2019 Act made on 26 June 2019, the Applicant to provide a carbon footprint for the Proposed Development, separately providing carbon assessments for onshore and offshore facilities."

In response to the request from the ExA, an assessment of the greenhouse gas (including carbon dioxide) footprint of activities associated with the Norfolk Boreas project has been undertaken. This assessment quantified emissions associated with the project as a whole, and separately for the onshore and offshore components. Existing literature was used to place the outcomes of the Norfolk Boreas GHG footprint in the context of the wider offshore wind industry, and to provide a benchmark against which the outcomes of the assessment were verified.

The GHG assessment considered emissions from construction, operation and decommissioning activities associated with Norfolk Boreas. GHG calculations were derived using available information at the time of the assessment, which included embodied emissions in materials, marine vessels, road traffic vehicle movements and the use of plant and equipment.

The results of the assessment determined that the GHG footprint of the Norfolk Boreas project would be approximately 1,860,339 tonnes under Scenario 1, and 1,939,031 tonnes under Scenario 2 over the project lifetime (30 years). Using the expected energy totals generated over the lifespan of the project, the GHG intensity for the Norfolk Boreas would be approximately 7.48 g/CO_2e/kWh under Scenario 1, and 7.80 g/CO_2e/kWh under Scenario 2. These figures are within the range (albeit at the lower end) of carbon intensity identified for previous projects.

Using future estimations of the GHG intensity of the UK energy mix in 2027, the expected first operational year, the carbon payback of emissions from the Norfolk Boreas project are likely to be within 1 to 2 years from when the Norfolk Boreas starts to produce electricity for the UK grid.

Norfolk Boreas Greenhouse Gas Footprint

1 Introduction

1.1 Background

The UK Government has committed to achieving a trajectory to net zero greenhouse gas (GHG) emissions status by the year 2050, in compliance with advice given by the Climate Change Committee (CCC)[1] and the Climate Change Act 2008. This is to play its international part in limiting global temperature increases to less than +2º Celsius and, ideally, closer to +1.5º Celsius. As a part of attaining this goal, the UK will need to decarbonise its electricity supply industry (ESI), moving away from reliance upon oil, coal and gas, replacing these with nuclear and renewable sources of energy such as wind, solar and biomass. There may still be a requirement, at least in the medium term, to combust some fossil fuels under controlled conditions but emissions would be subject to carbon capture and storage (CCS).

During 2019, 57% of electricity consumed in the UK was generated by nuclear, solar, biomass and wind, with the remaining 43% generated by fossil fuels. 26.5% was generated by wind farms alone[2,3]. The current installed generating capacity of onshore and offshore wind farms is 23 gigawatts (GW): 13.65 GW of onshore capacity and 10.4 GW of offshore capacity[4]. The Norfolk Boreas project would contribute significantly to the decarbonisation of the UK energy supply.

Additional capacity is in the planning and construction stage and Norfolk Boreas offshore windfarm, the Development Consent Order (DCO) for which is presently under Examination by the Examining Authority (ExA), would contribute a further 1.8 GW of capacity which is energy for approximately two million homes or 2% of the UK's annual energy demand . As part of the Examination of Norfolk Boreas, the ExA published a Rule 17 request for information on the 20th July 2020. The Rule 17 letter[5] included the following request from the Applicant (reference R17.1.31):

"In support of the 'zero net carbon' Climate Change Act 2008 (2050 Target Amended) Order 2019 Act made on 26 June 2019, the Applicant to provide a carbon footprint for the Proposed Development, separately providing carbon assessments for onshore and offshore facilities."

1.2 This Report

The study reported on here was commissioned by Norfolk Boreas Limited to answer the request for further information reference 17.1.31. This report contains a quantified assessment of GHG emissions over the lifetime of the proposed Norfolk Boreas offshore wind farm project, considering onshore and offshore components of the development and detailing construction, operation & maintenance and decommissioning aspects.

The approach to this GHG assessment, including the methodology, results and conclusions has been developed by HaskoningDHV UK Limited independently of Norfolk Boreas or Vattenfall Wind Power Limited. HaskoningDHV UK Limited have extensive experience in undertaking such assessments and have conducted full Life Cycle Assessments for other Nationally Significant Infrastructure Projects.

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[1] https://www.theccc.org.uk/publication/net-zero-the-uks-contribution-to-stopping-global-warming/
[2] https://www.nationalgrid.com/britain-hits-historic-clean-energy-milestone-zero-carbon-electricity-outstrips-fossil-fuels-2019
[3] https://www.independent.co.uk/news/science/wind-power-coal-climate-change-renewable-energy-a9273541.html
[4] https://www.renewableuk.com/page/UKWEDhome
[5] https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010087/EN010087-002276-200717_NORB_Rule_17.pdf

1.2.1 Context

The construction, operation & maintenance 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 and their associated physical infrastructure; and
- Carbon and other GHG emissions arising from combustion of fuels and energy used during installation and construction, operating and maintaining the project components over its lifetime and in decommissioning.

There are inherent uncertainties associated with carrying out GHG footprint assessment for offshore wind power projects, although the approach to determining emissions from individual source groups (see **Section 2.2**) is well defined. A report published by the University of Edinburgh in 2015[6] 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[6]. This report provided useful context for the Norfolk Boreas GHG assessment, and benchmark figures which were used to verify the outcomes of the assessment. **Table 1-1** provides a summary of the percentage of total GHG emissions associated with the different phases of a wind farm development as provided within the report.

Table 1-1: Summary of Offshore Wind Farm GHG emissions[6]

Phase	% of Total GHG Emissions
Manufacture and Installation	78.4
Operation and Maintenance	20.4
Decommissioning	1.2

The report showed that the greater proportion of emissions (78.4%) are associated with the manufacture and installation of the wind farm components, with 20.4% arising during operation and maintenance. Decommissioning accounted for only 1.2% of total life cycle GHG emissions. A more detailed breakdown of emissions is given in the Edinburgh University report for an offshore wind farm with steel foundations. This is reproduced in **Table 1-2**.

[6] https://www.climatexchange.org.uk/media/1461/main_report_-_life_cycle_costs_and_carbon_emissions_of_offshore_wind_power.pdf

Table 1-2: Further Detailed Breakdown of GHG emissions[6]

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

Of the above, the 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%[7]. This may appear to be unexpectedly high but the vessel movements contribution is associated with a 20-year operational life-span of the wind farms considered in the studies. Emissions derived from helicopter movements (2.4%), spare parts (3.7%) and dismantling and disposal (1.2%) are all small, in comparison.

Additional analysis of the data extracted from the 18 technical studies expressed the GHG emissions as grammes (g) of carbon dioxide equivalents – CO_2e - per kilowatt-hour (kW h) of electricity generated. These were found to vary quite widely, between approximately 5 and 33 g CO_2e kW h^{-1}. There was no clear relationship between the metrics and either turbine rating (in MW) or capacity factor. A further study in 2012[8], 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 kW h of electricity generated varied between approximately 7 and 23 g CO_2e kW h^{-1}, with a mean value of around 12 g CO_2e kW h^{-1}.

To place these metrics into context, comparable values for electricity generation by gas are around 400 g CO_2e kWh^{-1} (33.3 times that of offshore wind) and, for coal, approximately 1,100 g CO_2e kWh^{-1} (91.6 times that of offshore wind).

Although robust and fit for the purpose of request, this report should not be taken to be a comprehensive, detailed Life Cycle Analysis (LCA) as defined by ISO 14040:2006[9]. This report provides an approximation of GHG emissions arising from Norfolk Boreas using readily information data directly relevant to the project.. Therefore, assumptions and simplifications to the methodology were made in certain areas and a precautionary approach was adopted for the assessment to allow for this. These assumptions and simplifications are referred to at the relevant point in **Section 2.3**.

[7] Shipping GHG emissions associated with installation of the wind farm components are included within the first three categories in Table 1.2.
[8] https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1530-9290.2012.00464.x
[9] ISO 14040:2006 defines LCA as "A systematic set of procedures for compiling and examining the inputs and outputs of materials and energy and the associated environmental impacts directly attributable to the functioning of a product or service system throughout its life cycle.

2 Methodology

2.1 Approach

In response to the request for further information, reference R17.1.31, this assessment considered GHG emissions from the Norfolk Boreas project. In this assessment, the term 'GHG' or 'carbon' encompasses 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)[10]. 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)[11].

Emissions were quantified for the construction, operational and decommissioning phases of the Norfolk Boreas project to determine GHG emissions. Carbon emissions per kWh of energy generated by the Norfolk Boreas project were also calculated.

The system boundary of the carbon footprint includes material extraction and manufacturing, transport and installation, operation and maintenance and end of life and decommissioning. A schematic diagram of the project boundary is provided in **Figure 1**.

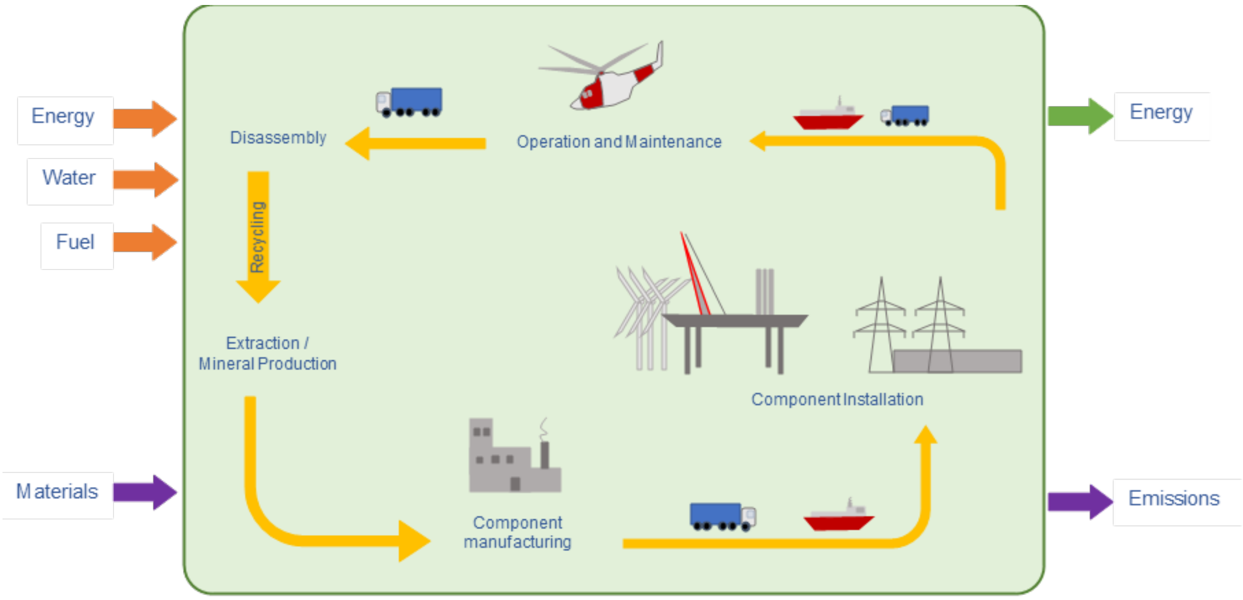

Figure 1: System Boundary for the Norfolk Boreas GHG Assessment

2.2 Emission Calculations

GHG emissions for the Norfolk Boreas project were quantified for the onshore and offshore components separately as per the request for further information reference R17.1.31. The emission sources were categorised into four main source groups, as detailed in **Table 2-1**.

[10] NF_3 was incorporated in the second Kyoto Protocol compliance period in 2012
[11] 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.

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Table 2-1: 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 the Norfolk Boreas Project. The components that were considered included the main infrastructure associated with Norfolk Boreas, such as foundations, wind turbines, cables (onshore and offshore), offshore electrical platforms, the onshore project substation and the National Grid substation extension. 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 the Norfolk Boreas Project was obtained from existing literature.
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 the Norfolk Boreas Project. 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 Operation and Maintenance (O&M) phase were also quantified.
3	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, the staff travel during construction and operation.
4	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 Norfolk Boreas project. This included the landfall, cable installation, substation and works at the National Grid substation.

Activities during the decommissioning phase are unknown at this stage, emissions from decommissioning were therefore derived from previous studies[6], which quantified them to be approximately 1.2% of the carbon footprint.

Vattenfall Wind Power Limited (the parent company of Norfolk Boreas Limited) is also developing Norfolk Vanguard, a 'sister project' to the Norfolk Boreas project. To minimise impacts associated with onshore construction works for the two projects, Vattenfall Wind Power Limited is proposing to carry out enabling works under the Norfolk Vanguard Development Consent Order (DCO) for both projects at the same time. Whilst it is anticipated that Norfolk Vanguard will be constructed, Norfolk Boreas needs to consider the possibility that Norfolk Vanguard does not proceed to construction. Therefore, the Norfolk Boreas DCO is seeking to consent the following two alternative scenarios:

- **Scenario 1** – Norfolk Vanguard proceeds to construction and installs ducts and other shared enabling works for Norfolk Boreas.

- **Scenario 2** – Norfolk Vanguard does not proceed to construction and Norfolk Boreas proceeds alone. Norfolk Boreas undertakes all works required as an independent project.

Further details regarding the activities carried out under both scenarios are presented in the Environmental Statement (Chapter 5) for the Project [APP-218 of the Norfolk Boreas Examination Library[12]]. For the purposes of the carbon footprint assessment for the Norfolk Boreas project, emissions were calculated for both Scenario 1 and Scenario 2 for the onshore component.

The approach to quantifying GHG emissions for each of the source groups detailed in **Table 2-1** is provided below. Further details with respect to the origin of the values used within the GHG assessment are provided in **Appendix A**.

2.2.1 Embodied Emissions in Materials

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 Norfolk Boreas. GHG emissions were derived from quantities or volumes of known materials that will be used in construction, including the following infrastructure:

- Offshore;
  - Foundations (gravity base were included in the assessment as they would have the maximum GHG footprint; other foundation types within the design envelope such as monopiles would have a much lower GHG footprint.)
  - Offshore electrical platforms;
  - Wind turbines;
  - Scour and cable protection; and
  - Inter-array, interconnector and export cables;
- Onshore:
  - Landfall;
  - Export cable;
  - Onshore cable;
  - Onshore project substation
  - Works at National Grid substation; and
  - Overhead Line (OHL) works.

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 the Norfolk Boreas project (2024 – 2028). The quantities of each type of construction material to be used on site were obtained from the Project design team, and the relevant emission factors sourced from the Inventory of Carbon and Energy (ICE) database[13] (ICE, 2019). Precautionary assumptions were adopted with respect to material quantities to be used for each component of Norfolk Boreas which included contingency allowing for the worst case scenario of the design envelope to be accounted for.

There are many possible foundation types currently available or under design to support offshore wind turbines and/or offshore platforms. Emissions were quantified for both the monopile and gravity base foundation types in the carbon footprint assessment, as these are the lowest and most intensive GHG options for the Norfolk Boreas Project respectively.

[12] https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010087/EN010087-000897-Norfolk%20Boreas%20Examination%20Library%20PDF%20Version.pdf
[13] ICE Database (2019), University of Bath Inventory of Carbon and Energy (ICE) Version 3.0

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 vehicle source group, detailed in **Section 2.2.3**. This source group also included emissions associated with the removal of excavated materials from the site.

2.2.2 Marine Vessels

Marine vessels will be used to bring materials and components to the offshore project area, install infrastructure (foundations, wind turbines, substations and cables), provide crew accommodation and support during construction, commissioning and operation/maintenance.

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

Marine vessel information was provided by the design team for the project to derive estimated fuel consumption during construction and operation of Norfolk Boreas. Emission factors for marine gas oil (MGO), in kg CO_2e / kW h were obtained from the Department for Business, Energy and Industrial Strategy (BEIS)[14]. For some 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, engine sizes for representative vessels were obtained to determine fuel consumption.

The installation vessels for offshore wind projects are specialised for the implementation of components such as wind turbines and substations. The vessels include crane lifting equipment and other plant and machinery that are required during the installation process. It was assumed that this specialised equipment is also powered by marine gas oil, and this was also included within the fuel consumption calculations.

Emissions were also quantified from the O&M phase over the anticipated life span of the Norfolk Boreas project (30 years).

Some elements of the data used to calculate GHG emissions from marine vessels is confidential at this stage, therefore a detailed breakdown of information used to derive GHG emissions from this source is unavailable.

2.2.3 Road Traffic Vehicles

Road traffic vehicle movements associated with the construction and O&M phases of the Norfolk Boreas 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 also during the O&M phase.

Anticipated changes to the fleet make up (in terms of fuel and euro standards) were incorporated into each future year 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

[14] BEIS (2020), Government Conversion Factors for Company Reporting of Greenhouse Gas Emissions, available from URL: https://www.gov.uk/government/collections/government-conversion-factors-for-company-reporting

from the Department for Transport (DfT 2019) WebTAG data[15]. 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.

Emission factors for each vehicle type considered in the assessment were obtained from BEIS[14], 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.

Distances travelled for both Scenarios 1 and 2 were calculated for HGV movements and staff travel according to the following methodology:

HGV movements

- Total project HGV vehicle movements were collated from the GHD Transport Assignment on Indicative Construction Programme as provided within Appendix 24.7 (Scenario 1) and Appendix 24.22 (Scenario 2) of the Submitted ES;
- As the origins of materials are currently unknown, the methodology follows that which was presented in Chapter 24: Traffic and Transport of the ES [APP-237 of the Norfolk Boreas Examination library][12], which utilises three origin ports (Kings Lynn, Great Yarmouth and Lowestoft). The distances (km) from the ports have been calculated to each of the project infrastructure destination sites for each stage of construction;
- The total HGV movements were multiplied by the calculated distances and this provides the total HGV km travelled for each origin port; and
- The final total HGV km travelled per scenario has been calculated by averaging the three origin port HGV kms travelled totals.

Staff travel

- Total project employee vehicle movements were collated from the GHD Transport Assignment on Indicative Construction Programme as provided within Appendix 24.7 (Scenario 1) and Appendix 24.22 (Scenario 2) of the Submitted ES;
- In recognition of the large geographical area and rural nature of the traffic and transport study area it has been assumed, as a precautionary approach, that all construction employees travel by single occupancy vehicles;
- Three destination locations as presented in Chapter 24 of the ES [APP-237 of the Norfolk Boreas Examination library] were utilised:
    - Origin Data Set A – Near Necton utilised for Substation vehicle movements
    - Origin Data Set B – Near Cawston/Reepham utilised as the central point for the onshore cable route vehicle movements
    - Origin Data Set C – Near Happisburgh utilised for Landfall vehicle movements;
- The travel distances were derived from available postcode cluster data as presented in Appendix 24.8 and 24.9 from the ES to each 'Origin Data Set', and were calculated for both in-migrant (70%) and local residential workforce (30%); and
- The distances were then multiplied by the total employee vehicle movements and the percentage distribution for resident and in-migrant employees from outside of Norfolk (Appendix 24.10 in the ES).

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[15] Department for Transport (DfT) (2019a) Transport Analysis Guidance, WebTAG A1.3.9: Proportions of vehicle kilometres by fuel type. May 2019

GHG emissions from road traffic vehicles during construction were calculated for both Scenario 1 and Scenario 2 separately.

During the operational phase of the project, traffic movements would be limited to those generated by the daily operation and periodic maintenance at the onshore project substation and at link boxes along the onshore cable route. It was therefore assumed that there would be an average two traffic movements per week during 30 year lifespan of the operational phase of the project, which is considered to be a precautionary approach.

2.2.4 Plant and Equipment

Fuel consumption associated with the operation of NRMM for the onshore components of the project was 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 for each work area, along with their anticipated duration and programme, were provided by the Applicant's design team, which includes earth moving equipment, cranes and specialist equipment such as cable pulling machinery and piling rigs.

The anticipated fuel demand over the duration of construction was calculated and the emission factor for gas oil consumption was obtained from BEIS[14] to derive GHG emissions.

The following assumptions were adopted in the assessment:

- Each item of plant and equipment would operate throughout the consented working hours for the project (66 hours). An on-time factor, consistent with Appendix 24.4 and 24.6 of the Environmental Statement, 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%.

GHG emissions from plant and equipment were calculated for both Scenario 1 and Scenario 2 separately.

2.3 Limitations

The key limitations of the assessment, and how they have been addressed are listed in **Table 2-2**.

Table 2-2: 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 assessment.	Quantities of the main and most GHG intensive material quantities were included in the assessment. Furthermore, precautionary assumptions were adopted for quantities of known materials, particularly for concrete and scour protection quantities.
2	Lack of emission factors for future year activities, such as fuel consumption and material extraction.	The most recent and available emission factors were used in the assessment to provide a precautionary scenario.
3	The origin Port of some of the marine vessels was not known at the time of assessment, which affects how far the vessels have to travel to the	As the majority of emissions will be released from vessels whilst at the site during installation, changes to the transit time for marine vessels will have a limited effect in terms of

ID	Limitation	Action Taken
	site, and subsequently the quantity of emissions released.	the overall GHG footprint. However, the most likely origin ports known at the time of the assessment were used to derive GHG emissions during transit.
4	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.
5	Specific nature and composition of some materials such as the type of concrete 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.

3 Results

GHG emissions associated with each source group listed in **Table 2-1** is provided for both Scenario 1 and Scenario 2 in **Table 3-1**. The results presented assume the use of a Gravity Based Foundation for the wind turbines, which have a significantly higher carbon footprint than the monopile foundations. The results shown in **Table 3-1** includes both onshore and offshore elements of Norfolk Boreas.

Table 3-1: GHG Emissions Associated with Each of the Source Groups Considered in the Assessment

Source Group	Scenario 1		Scenario 2	
	GHG Emissions (Tonnes CO_2e)	Percentage of Carbon Footprint	GHG Emissions (Tonnes CO_2e)	Percentage of Carbon Footprint
Construction - Embodied emissions in materials (offshore and onshore)	1,481,916	79.7%	1,550,369	80.0%
Construction - Marine vessels (offshore)	169,843	9.1%	169,843	8.8%
Construction - Road traffic vehicles (onshore)	4,600	0.2%	12,284	0.6%
Construction - Plant and equipment (onshore)	3,245	0.2%	4,383	0.2%
Operation	167,248	9.0%	167,248	8.6%
Decommissioning	33,486	1.2%	34,903	1.2%
Total	**1,8060,339**	**100%**	**1,939,031**	**100%**

The results presented in **Table 3-1** highlight that embodied emissions associated with extraction and manufacture processed within materials used on the Norfolk Boreas Project forms the largest component of the carbon footprint. As some of the onshore enabling works will be carried out for the Norfolk Boreas Project by Norfolk Vanguard, GHG emissions are lower for Scenario 1 when compared to Scenario 2.

In response to the examiner's request for further information, emissions associated with the onshore and offshore components are provided separately in **Table 3-2**.

Table 3-2: GHG Emissions Associated with the Onshore and Offshore Components

Project Component	Source Group					
	Embodied emissions in materials	Marine vessels	Road traffic vehicles	Plant and equipment	Operation	Total
Offshore	1,429,366	169,843	-	-	165,685	1,599,239
Onshore (Scenario 1)	52,520	-	4,600	3,245	1,563	60,365
Onshore (Scenario 2)	120,973	-	12,284	4,383	1,563	137,640

The results in **Table 3-2** show that the offshore component has the larger GHG footprint of the Norfolk Boreas Project.

4 Discussion

The results presented in **Section 3** show that the GHG footprint for the Norfolk Boreas Project is 1,860,339 tonnes under Scenario 1, and 1,939,031 tonnes under Scenario 2 over the project lifetime (30 years). The GHG intensity of the Norfolk Boreas project was determined by dividing this figure by the anticipated energy produced over the lifespan of the project.

For the purposes of this assessment, a high level approach to estimating the amount of energy produced by the Norfolk Boreas Project was derived from that advocated by RenewableUK[16], where the installed capacity (1,800MW) is multiplied by the hours in the year and by the appropriate average load or capacity factor for the Project. For new build offshore projects, BEIS advises that the load factor is 58.4%[17]. An availability factor of 90% was also applied (as was used in Chapter 2 of the Norfolk Boreas ES (APP-215[18])), based on the ability of the wind farm, as a whole to generate power, given appropriate weather and grid conditions.

Annual energy generated by the Norfolk Boreas Project is therefore estimated to be approximately 8,200 GWh, and over the lifespan of the project of 30 years, 248,000 GWh. The GHG intensity for the Norfolk Boreas project is therefore 7.48 g/CO_2e/kWh under Scenario 1, and 7.80 g/CO_2e/kWh. When compared with other offshore windfarm life cycle studies[6, 8], the GHG intensity of the Norfolk Boreas Project is within the range (but towards the lower end) of the carbon intensity identified in previous projects. These studies considered projects which are now 5 - 10 years old, and there have been significant innovations and efficiencies in terms of technology, logistics and resources that have been adopted into more recent and future offshore wind farms. Therefore, it would be expected that the Norfolk Boreas project would be towards the lower end of GHG intensity values identified in these previous studies.

The estimated GHG footprint of Norfolk Boreas, which includes emissions from all components of the project including extraction of materials, construction, operation and decommissioning, is approximately 1.9 million tonnes of CO_2e.

Using future estimations of the GHG intensity of the UK energy mix in 2027, the expected first operational year, the carbon payback of emissions is likely to be 1 – 2 years from when the Norfolk Boreas Project starts to produce electricity for the UK grid. Therefore, for the remainder of the project lifetime, Norfolk

[16] www.renewableuk.com/page/UKWEDExplained
[17] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/799074/Allocation_Round_3_Allocation_Framework__2019.pdf
[18] https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010087/EN010087-000388-6.1.2%20Environmental%20Statement%20Chapter%202%20Need%20for%20the%20Project.pdf

Boreas will produce zero GHG energy, which also accounts for future operational and decommissioning emissions.

Vattenfall have carried out similar assessments for their other offshore wind farm projects. For these projects, which are generally at a more advanced stage (and therefore have a more advanced supply chain) than Norfolk Boreas, indicate that carbon payback would occur within a single year. The reason that this study estimates a slightly longer payback time (1 - 2 years) is due to the fact that a precautionary approach has been taken due to fact that the final supply chain for the project is not yet known. For example, if monoplies are included in the calculations instead of gravity base foundations that would reduce the carbon footprint of the project by nearly 500,000 tonnes which would mean that payback would then be within a single year.

5 Summary

A GHG assessment was carried out for the Norfolk Boreas project in response to the ExAs request for further information R17.1.31 made as part of the Norfolk Boreas examination. The GHG assessment considered emissions from the extraction and manufacture of materials, marine vessel and road traffic movements, and the use of construction plant and equipment.

GHG emissions from construction and the 30 year operation of the Norfolk Boreas Project are anticipated to be up to 1,860,339 tonnes under Scenario 1, and up to 1,939,031 tonnes under Scenario 2. The largest GHG contribution is embodied emissions within materials to be used during construction, particularly in the offshore components of the project.

The GHG intensity of energy produced by the Norfolk Boreas project was anticipated to be between 7.48 – 7.80 g/CO_2e/kWh. This is towards the lower range of previous studies for offshore wind farms and therefore the carbon payback of emissions is likely to be 1 – 2 years from when the Norfolk Boreas Project starts to produce electricity for the UK grid. Consequently, Norfolk Boreas will produce zero GHG energy following this initial carbon payback period of 1 – 2 years.

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Appendix A – GHG Emissions Calculation

A1 – Embodied Emission in Materials

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

Table A1: Embodied GHG in Materials Emission Factors

Material	Emission Factor ($kgCO_2e/kg$, unless stated)	Source	Notes
Aggregate (general UK)	0.00747	ICE DB V3.0 Nov 2019	Aggregate (general UK mix of land won, marine, secondary and recycled, bulk, loose
Aluminium (general, European mix, Inc Imports)	6.67	ICE DB V3.0 Nov 2019	
Aluminium (general, worldwide)	13.1	ICE DB V3.0 Nov 2019	
Asphalt	14.2	ICE DB V3.0 Nov 2019	Based on Road surface, asphalt, 3% (bitumen binder content (by mass))
Black carbon	0.39	Probas, 2009[19]	
CBS	0.11	ICE DB V3.0 Nov 2019	Based on closest mix which is 1:6 cement: sand under "Mortar"
Ceramic (general)	0.7	ICE DB V3.0 Nov 2019	
Ceramic (fittings)	1.14	ICE DB V3.0 Nov 2019	
Vitrified clay pipe DN 100 & DN 150	0.46	ICE DB V3.0 Nov 2019	
Vitrified clay pipe DN 200 & DN 300	0.5	ICE DB V3.0 Nov 2019	
Vitrified clay pipe DN 500	0.55	ICE DB V3.0 Nov 2019	
Concrete (general)	0.103	ICE DB V3.0 Nov 2019	
Concrete (2% reinforced)	0.24	Harrison et al, 2010[20]	
Copper (EU tube and sheet)	2.71	ICE DB V3.0 Nov 2019	
Fencing	0.452	ICE DB V3.0 Nov 2019	Timber, closed panel timber frame system, no carbon storage
Fibre reinforced plastic	4.84	ICE DB V3.0 Nov 2019	Emission factor for 'Polyurethane flexible foam' used
Fine paper	1.49	ICE DB V3.0 Nov 2019	

[19] ProBas (Prozessorientierte Basisdaten für Umweltmanagement-Instrumente), 2009. Russ Produktion aus Erdöl (Carbon black production from oil), Öko-Institut eV (Institute for Applied Ecology)., Freiburg, Germany. http://www.probas.umweltbundesamt.de
[20] https://www.research.ed.ac.uk/portal/files/21980985/Grid_Carbon_Footprint_Paper.pdf

Material	Emission Factor ($kgCO_2e/kg$, unless stated)	Source	Notes
Geotextiles	4.2	ICE DB V3.0 Nov 2019	Emission factor for 'Damp Proof Course Membrane' used.
Grout	0.2	ICE DB V3.0 Nov 2019	Emission factor for 'Mortar 1:3 cement, sand mix' used
High density polyethylene (HDPE) pipe	2.52	ICE DB V3.0 Nov 2019	
Insulated materials	1.86	ICE DB V3.0 Nov 2019	Emission factor for 'General Insulation' used
Lead	1.67	ICE DB V3.0 Nov 2019	
Mineral oil	3.09	McManus et al, 2004[21],	
Paint	2.91	ICE DB V3.0 Nov 2019	Based on 'General' emission factor
Polyethylene	2.54	ICE DB V3.0 Nov 2019	Emission factor for 'General Polyethylene' used
Quarried rock (scour protection)	0.079	ICE DB V3.0 Nov 2019	
SF6	9	Campbell and McCulloch, 1998[22]	
Steel (world average)	1.55	ICE Cement, Mortar and Concrete Model - V1.1 28 Nov 2019	
Steel (Europe recycled)	0.73	ICE Cement, Mortar and Concrete Model - V1.1 28 Nov 2019	
Steel (global seamless tube)	2.13	ICE DB V3.0 Nov 2019	
Steel (wire rod)	2.27	ICE DB V3.0 Nov 2019	
Surface protection material	0.079	ICE DB V3.0 Nov 2019	
Transformer Oil	3,221 (kg CO2e per tonne)	BEIS, 2020, Greenhouse gas reporting: conversion factors	Assumed to be fuel oil
Water	0.0008	ICE DB V3.0 Nov 2019	
Wood	0.493	ICE DB V3.0 Nov 2019	Emission factor for 'average timber' used.

[21] https://www.research.ed.ac.uk/portal/files/21980985/Grid_Carbon_Footprint_Paper.pdf
[22] https://www.research.ed.ac.uk/portal/files/21980985/Grid_Carbon_Footprint_Paper.pdf

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A2 – Road Traffic Vehicles

The methodology used to derive total distance travelled by HGVs and employees in private cars is detailed in **Section 2.2.3**. The travel distances used in the assessment for Scenario 1 and Scenario 2 are presented in **Table A2**.

Table A2: Distances Travelled by HGVs and Employees during Construction

Norfolk Boreas Scenarios	HGVs (km Travelled)	Employees (km Travelled) Car
Scenario 1	3,593,391	5,630,045
Scenario 2	11,208,749	9,668,905

The proportion of diesel, petrol and electric cars in the UK fleet for the first year of construction was obtained from DfT 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[14].

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

Vehicle	Fleet Composition (%)	Vehicle Emission Factor ($kgCO_2e/km$)	Emission Factor Used in the Assessment ($kgCO_2e/km$)
Diesel car	49.5	0.28	0.26
Petrol Car	47.7%	0.27	
Electric Car	6.8%	0.00	

It was assumed that all HGVs used on the project were diesel powered. The emission factor for HGV movements was obtained from BEIS[14], and was 0.87 $kgCO_2e/km$.

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A3 – Plant and Equipment

Plant and equipment used in Scenario 1 is provided for each component in **Tables A4 – A7**.

Table A4 – Plant and Equipment used for Onshore Substation (Scenario 1)

Name	No.	On time Correction	Equipment
Tracked Excavator	2	75%	JCB Rubber Tyred Excavator (Wheeled Excavator / Loader)
Backhoe Loader	2	75%	CAT320 (Backhoe Excavator (Med))
Bulldozer	2	75%	D6 Dozers (Dozer (Med))
Dumper	2	75%	Small Dumper
Mobile Crane	2	75%	50t Mobile Crane
Cement Mixer Truck (Discharging)	1	50%	Concrete Truck Mixers
Truck Mounted Concrete Pump and Boom Arm	1	50%	Concrete Pumps
Piling	1	75%	Drilling Rigs (Piling)

Table A5 – Temporary Access Tracks and Pre-Construction Work (Scenario 1)

Name	No.	On time Correction	Equipment
Bulldozer	1	75%	D6 Dozers (Dozer (Med))
Tracked Excavator	1	75%	JCB Rubber Tyred Excavator (Wheeled Excavator / Loader)
Dump Truck	1	75%	Small Dumper
Asphalt spreader and road roller	1	75%	Asphalt pavers
Road Roller	1	75%	Road rollers

Table A6 – Landfall (Scenario 1)

Name	No.	On time Correction	Equipment
Tracked Excavator	1	50%	JCB Rubber Tyred Excavator (Wheeled Excavator / Loader)
Backhoe Loader[1]	1	50%	CAT320 (Backhoe Excavator (Med))
Bulldozer	1	50%	D6 Dozers (Dozer (Med))
Dumper[1]	1	50%	Small Dumper
Mobile Crane	1	25%	Mobile Cranes
Cement Mixer Truck (Discharging)	1	25%	Concrete Truck Mixers

Name	No.	On time Correction	Equipment
Truck Mounted Concrete Pump and Boom Arm	1	25%	Concrete Truck Mixers
Piling*	1	10%	Drilling Rigs (piling)
Drilling Rig[1]	1	75%	Drilling Rigs (piling)
Water Pump[1]	1	75%	Centrifugal Water Pump
Generator[1]	1	100%	Construction Diesel Generator

Table A7 – Cable Pulling (Scenario 1, per Workfront)

Name	No.	On time Correction	Equipment
Conveyor Drive Unit	1	100%	Geared Motor Drive Unit
Field Conveyor (Rollers)	2	100%	Assumed to be Powered by the Drive Unit
Tracked Excavator	1	50%	JCB Rubber Tyred Excavator (Wheeled Excavator / Loader)
Cement Mixer Truck (Discharging)	1	50%	Concrete Truck Mixers
Dump Truck	1	50%	Small Dumper
Water Pump	1	75%	Centrifugal Water Pump
Generator	1	100%	Construction Diesel Generator

Plant and equipment used in Scenario 1 is provided for each component in **Tables A8 – A13.**

Table A8 – Plant and Equipment used for Onshore Substation (Scenario 2)

Name	No.	On time Correction	Equipment
Tracked Excavator	2	75%	JCB Rubber Tyred Excavator (Wheeled Excavator / Loader)
Backhoe Loader	2	75%	CAT320 (Backhoe Excavator (Med))
Bulldozer	2	75%	D6 Dozers (Dozer (Med))
Dumper	2	75%	Small Dumper
Mobile Crane	2	75%	50t Mobile Crane
Cement Mixer Truck (Discharging)	1	50%	Concrete Truck Mixers
Truck Mounted Concrete Pump and Boom Arm	1	50%	Concrete Pumps
Piling	1	75%	Drilling Rigs (Piling)

Table A9 – Plant and Equipment used for Duct Installation (Scenario 2)

Name	No.	On time Correction	Equipment
Bulldozer	1	75%	D6 Dozers (Dozer (Med))
Dump Truck	1	75%	Small Dumper
Tracked Excavator	1	75%	JCB Rubber Tyred Excavator (Wheeled Excavator / Loader)
Generator	1	100%	Construction Diesel Generator
Water Pump	1	75%	Centrifugal Water Pump

Table A10 – Temporary Access Tracks and Pre-Construction Work (Scenario 2)

Name	No.	On time Correction	Equipment
Bulldozer	1	75%	D6 Dozers (Dozer (Med))
Tracked Excavator	1	75%	JCB Rubber Tyred Excavator (Wheeled Excavator / Loader)
Dump Truck	1	75%	Small Dumper
Asphalt Spreader and Road Roller	1	75%	Asphalt Pavers
Road Roller	1	75%	Road Rollers

Table A11 – Landfall (Scenario 2)

Name	No.	On time Correction	Equipment
Tracked Excavator	1	50%	JCB Rubber Tyred Excavator (Wheeld Excavator / Loader)
Backhoe Loader	1	50%	CAT320 (Backhoe Excavator (Med))
Bulldozer	1	50%	D6 Dozers (Dozer (Med))
Dumper	1	50%	Small Dumper
Mobile Crane	1	25%	Mobile Cranes
Cement Mixer Truck (Discharging)	1	25%	Concrete Truck Mixers
Truck Mounted Concrete Pump and Boom Arm	1	25%	Concrete Truck Mixers
Piling	1	10%	Drilling Rigs (Piling)
Drilling Rig	1	75%	Drilling Rigs (Piling)
Water Pump	1	75%	Centrifugal Water Pump
Generator	1	100%	Construction Diesel Generator

Table A11 – Trenchless Crossing (Scenario 2)

Name	No.	On time Correction	Equipment
Tracked Excavator	1	50%	JCB Rubber Tyred Excavator (Wheeled Excavator / Loader)
Backhoe Loader	1	50%	CAT320 (Backhoe Excavator (Med))
Bulldozer	1	50%	D6 Dozers (Dozer (Med))
Dumper	1	50%	Small Dumper
Mobile Crane	1	25%	Mobile Cranes
Cement Mixer Truck (Discharging)	1	25%	Concrete Truck Mixers
Truck Mounted Concrete Pump and Boom Arm	1	25%	Concrete Truck Mixers
Piling	1	10%	Drilling Rigs (Piling)
Drilling Rig	1	75%	Drilling Rigs (Piling)
Water Pump	1	75%	Centrifugal Water Pump
Generator	1	100%	Construction Diesel Generator

Table A12 – Mobilsation Area (Scenario 2)

Name	No.	On time Correction	Equipment
Tracked Excavator	1	25%	JCB Rubber Tyred Excavator (Wheeled Excavator / Loader)
Bulldozer	1	25%	D6 Dozers (Dozer (Med))
Dumper	1	25%	Small Dumper
Generator	1	100%	Construction Diesel Generator

Table A13 – Cable Pulling (Scenario 2, per Workfront)

Name	No.	On time Correction	Equipment
Conveyor Drive Unit	1	100%	Geared Motor Drive Unit
Field Conveyor (Rollers)	2	100%	Assumed to be Powered by the Drive Unit
Tracked Excavator	1	50%	JCB Rubber Tyred Excavator (Wheeled Excavator / Loader)
Cement Mixer Truck (Discharging)	1	50%	Concrete Truck Mixers
Dump Truck	1	50%	Small Dumper
Water Pump	1	75%	Centrifugal Water Pump
Generator	1	100%	Construction Diesel Generator

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 0.257 kgCO2e/kWh[14]. All plant were assumed to operate at an average load factor of 0.75.