MachairWind Offshore Windfarm

Appendix 19.1 Greenhouse Gas Assessment Methodology

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Glossary of Acronyms

Term	Definition
BEIS	Department for Business, Energy and Industrial Strategy
CFE	Controlled Flow Evacuation
CO_2	Carbon Dioxide
CTV	Crew Transfer Vessel
DESNZ	Department for Energy Security and Net Zero
ECC	Export Cable Corridor
EIA	Environmental Impact Assessment
EIAR	Environmental Impact Assessment Report
EPD	Environmental Product Declaration
GHG	Greenhouse Gas
GloMEEP	Global Maritime Energy Efficiency Partnerships Project
GWP	Global Warming Potential
HDPE	High-Density Polyethylene
IAC	Inter-Array Cable
ICE	Inventory of Carbon and Energy
IEA	International Energy Agency
IEMA	Institute of Environmental Management and Assessment
IPCC	Intergovernmental Panel on Climate Change
ISEP	Institute of Sustainability and Environmental Professionals
ISV	Installation Vessel
Kg	Kilogram
LCA	Lifecycle Assessment
LCV	Light Construction Vessel
MGO	Marine Gas Oil
NREL	National Renewable Energy Laboratory
OnTDA	Onshore Transmission Development Area
OSP	Offshore Substation Platform
PET	Polyethylene terephthalate
PVC	Polyvinyl Chloride
SF_6	Sulphur Hexafluoride
SOV	Service Operation Vessel
TSV	Trenching Support Vessel

Term	Definition
US EPA	United States Environmental Protection Agency
WDA	Windfarm Development Area
WTG	Wind Turbine Generator

Glossary of Terms

Term	Definition
Cable protection	Protective measure to minimise the effects of scour and hazards along the offshore cables (e.g. to prevent cable exposure or snagging of vessel anchors or fishing gear), as well as for protecting these cables at infrastructure crossing points.
Cradle to (factory) gate	The extraction, manufacture, and production of materials to the point at which they leave the factory gate of the final processing location.
Environmental Impact Assessment (EIA)	The process of evaluating the likely significant environmental effects of a proposed development over and above the existing circumstances (or 'baseline').
Greenhouse gas	A gas in the Earth's atmosphere that traps heat by absorbing and emitting infrared radiation, a process known as the greenhouse effect. Also known by the collective shorthand "carbon".
Inter-array cables (IACs)	Armoured cable containing electrical and fibre optic cores which link the wind turbine generators to each other and to the offshore substation platform(s).
MachairWind Offshore Windfarm	An offshore windfarm capable of exporting around 2 GW of renewable energy to the National Electricity Transmission System. MachairWind Offshore Windfarm comprises three Development Areas: • The WDA – located on the west coast of Scotland to the northwest of Islay and west of Colonsay; • The Offshore Export Cable Corridor – a preliminary boundary extending from the WDA to mean high water springs at a landfall location near Girvan, South Ayrshire; and • The Onshore Transmission Development Area – a preliminary boundary which extends landward from mean low water springs and includes the land required for the landfall of the offshore export cables and their route up to but not including the proposed high voltage direct current switching station which will be developed and constructed by Transmission Owner, ScottishPower Transmission. Separate consent and licence applications will be submitted for each Development Area.
National Electricity Transmission System	The high-voltage electricity power transmission network serving Great Britain which receives electricity from generators (such as offshore windfarms) and transmits that electricity to anywhere on the National Electricity Transmission System to satisfy demand.
Offshore export cable	Armoured cable containing electrical cores between the offshore substation platform(s) and landfall. Offshore export cables will include bundled fibre optic cables. The offshore export cables are subject to Marine Licence applications under the Marine (Scotland) Act 2010. The portion of the offshore export cable(s) located within the WDA is assessed as part of this MachairWind WDA EIA and a marine licence application to construct, alter or improve this portion has been submitted alongside the WDA application. A separate marine licence application will be submitted for the portion of the offshore export cable(s) from the WDA boundary to mean high water Mean High Water Springs.
Offshore Export Cable Corridor (ECC)	The preliminary boundary extending from the WDA to mean high water springs near Girvan, South Ayrshire and within which the offshore export cable(s) will be located. A separate marine licence application will be submitted for the offshore export cable(s) located within the Offshore ECC.
Offshore Substation Platform (OSP)	An offshore platform with a fixed foundation located within the WDA which houses electrical equipment such as transformers, switchgear, protection and control systems, and enables the windfarm's renewable electricity to be collected via inter-array cables and exported to the National Electricity Transmission System via offshore export cables.
Offshore Substation Platform (OSP) link cables	Electrical cables which link OSPs (if more than one OSP is required). These cables will include fibre optic cores or bundled fibre optic cables. OSP link cables will be wholly located within the WDA.

Term	Definition
Onshore Transmission Development Area (OnTDA)	The preliminary boundary which extends landward from mean low water springs and includes the land required for the landfall of the offshore export cables and their route up to but not including the proposed high voltage direct current switching station which will be developed and constructed by Transmission Owner, ScottishPower Transmission. This Transmission Owner is responsible for consenting the high voltage direct current switching station. Onward connections to the National Electricity Transmission System will be consented by National Grid Electricity Transmission and ScottishPower Transmission. Where relevant, these are considered as part of cumulative effects assessment in the EIA.
Operational life	The operational life is the expected length of time from final commissioning of the WDA until the cessation of commercial operations. This is anticipated to be 35 years.
Pre-construction works	Pre-construction works are activities undertaken prior to formal commencement of construction. Examples include survey works such as geotechnical and geophysical surveys and seabed preparation activities.
Scour protection	Protective measures to avoid sediment being eroded away from the base of the wind turbine generator foundations as a result of the flow of water.
The Applicant	The legal entity submitting consent applications for the MachairWind Offshore Windfarm, namely MachairWind Limited.
The Project	MachairWind Offshore Windfarm including all its Development Areas and associated infrastructure.
Windfarm Development Area (WDA)	The application boundary within the OAA where consent will be sought for the proposed WDA infrastructure. The WDA infrastructure is subject to Section 36 consent and marine licence applications (generation and transmission) which are being applied for separately from the Offshore ECC infrastructure and OnTDA infrastructure.
WDA infrastructure	The offshore generation and transmission infrastructure located within the WDA including but not limited to: WTGs, WTG fixed foundations (and associated scour protection), OSP(s), OSP fixed foundations (and associated scour protection), IACs, OSP link and offshore export cable(s) and their associated external cable protection (insofar as these are located within the WDA) and fibre optic cables.
Wind Turbine Generator (WTG)	A wind turbine generator which converts wind energy into electrical energy. Each wind turbine generator is a complex system composed of a high number of components. Typically, the main components include the rotor assembly (composed of three blades and a hub); the nacelle (containing a generator, shaft and gearbox, power electronic converter and transformer); and the tower (containing lifting equipment and the switchgear).

1 GREENHOUSE GAS ASSESSMENT METHODOLOGY

1.1 INTRODUCTION

1. This appendix presents the methodology to support **Chapter 19 Greenhouse Gas Assessment**. This appendix contains an overview of the activity data, emission factors and assumptions used to calculate greenhouse gas (GHG) emissions from the Windfarm Development Area (WDA). The methodology to calculate the whole Project, including the WDA, the Offshore Export Cable Corridor and the Onshore Transmission Development Area (OnTDA), is also detailed in this appendix. The GHG assessment has been undertaken in accordance with the Institute of Environmental Management & Assessment (IEMA)[1] Guide: Assessing Greenhouse Gas Emission and Evaluating their Significance (IEMA, 2022). The Carbon Trust guidance, Offshore Wind Industry Product Carbon Footprinting Guidance (Carbon Trust, 2024a) has also been considered for the GHG assessment.

1.1.1 GHG Emissions Sources for Offshore Windfarms

2. The construction, operation, maintenance, repowering, and decommissioning of offshore windfarm projects entail the release of GHG emissions from:

- Embodied carbon and GHGs from the WDA infrastructure. These are 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 turbines (and their associated physical infrastructure), cables, and any required spare parts, etc.; and
- Carbon and other GHG emissions arising from the combustion of fuel and energy used over a WDA's lifetime. Emissions in this assessment are associated with marine vessels, vehicles, helicopters, and plant and equipment.

3. To ensure an assessment of all the development areas is undertaken, a whole Project GHG assessment (i.e. the WDA infrastructure, Offshore Export Cable Corridor (ECC) and OnTDA together) is presented in the WDA Environmental Impact Assessment (EIA) Report (EIAR). The whole Project GHG assessment evaluates the net contribution of the Project as a whole to climate change, through consideration of GHG emissions arising from infrastructure associated with all component parts (e.g. WDA, Offshore ECC and OnTDA). The whole Project GHG assessment is iterative and will be updated in the Offshore ECC and OnTDA EIARs to utilise the most up to date information available at the time of preparing each EIAR.

4. There are a number of uncertainties associated with the provision of GHG footprint assessments for offshore windfarm projects at this stage, such as the level of embodied carbon in materials and components which is dependent on the specific manufacturer/supplier, and emissions from mobile plant and equipment can be difficult to predict and may vary over time. However, the approach to determine emissions from individual source groups is well defined in The Carbon Trust: Offshore Wind Industry Product Carbon Footprinting Guidance (Carbon Trust, 2024a) and is adopted in this assessment. The assumptions and limitations of the approach to calculating GHG emissions in the assessment are detailed in Section 19.5.1.2 of **Chapter 19 Greenhouse Gas Assessment**.

1.1.2 GHG Intensity of Offshore Windfarm Energy

5. In a report investigating carbon emissions of wind power (Thomson and Harrison (2015), the GHG emissions intensity (expressed as grams (g) of CO_2e per kilowatt-hour (kWh) of electricity generated) of electricity from 18 technical studies was analysed. These were found to vary quite widely, between

[1] Now the Institute of Sustainability and Environmental Professionals (ISEP)

approximately 5 and 33 g CO_2e per kWh. There was no clear relationship between the metrics for either turbine rating (in MW) or capacity factor.

6. A further study (Dolan and 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 inconsistencies. 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 per kWh, with a mean value of around 12 g CO_2e per kWh.

7. It is noted that these studies were published in 2012 and 2015, and it is acknowledged that there have subsequently been significant advances in the technology, infrastructure and components used for offshore windfarms. The energy intensities of a range of other studies post 2015 are presented in **Table 1.1**, which show a range from 7.8 to 25.5 g CO_2e per kWh.

Table 1.1 Review of average carbon emission per kWh

Windfarm sizes	Energy intensity (g CO_2e per kWh)	Source
12 x 5 MW	32	Chen *et al.* (2011), referenced in Bhandari *et al.* (2020)
N/A	6	International Energy Agency (IEA) World Energy Outlook (2012), referenced in Siemens Gamesa (n.d.) and Ørsted (2021)
100 x 2.5 MW	13.7	Arvesen and Hertwich (2012), referenced in Bhandari *et al.* (2020)
80 x 4 MW	10.9*	Bonou *et al.* (2016), referenced in Bhandari *et al.* (2020)
100 x 6 MW	7.8*	Bonou *et al.* (2016), referenced in Bhandari *et al.* (2020)
28 x 3.6 MW	25.5*	Yang *et al.* (2018), referenced in Bhandari *et al.* (2020)
*Offshore windfarm studies published from 2016 onwards		

8. While the GHG assessment of the WDA infrastructure is not a detailed lifecycle assessment (LCA), it adopts a precautionary approach and is robust and appropriate for an EIA. A full LCA has not been undertaken because it is not possible to fully define the supply chain for the WDA at this stage, and some information will be refined as the design progresses. Therefore, assumptions and simplifications to the methodology are made in certain areas, and a precautionary approach is adopted for the assessment to allow for this. These assumptions and simplifications are referred to in Section 19.5.1.2 of **Chapter 19 Greenhouse Gas Assessment**, and the worst-case scenario set out in Section 19.4.2 of **Chapter 19 Greenhouse Gas Assessment**.

1.2 WDA GHG ASSESSMENT METHODOLOGY

9. The WDA GHG assessment is based on the worst-case scenario detailed in Section 19.4.3 of **Chapter 19 Greenhouse Gas Assessment**. The scope of this document includes the methodology used to calculate the following emissions sources attributed to the Carbon Trust's lifecycle modules, which are detailed in **Table 1.2**. The methodology for deriving the avoided emissions (module D2) used in the GHG assessment considers the GHG emissions from the 'Do Nothing' scenario, outlined in Section 19.6.2 of **Chapter 19 Greenhouse Gas Assessment**.

Table 1.2 GHG assessment emission sources and lifecycle modules

Lifecycle Module	Emissions Source
A0 (Pre-construction)	Fuel and electricity consumption for pre-construction surveys and activities, including site preparation works (e.g., vehicles and vessels).
A1-A3 (Embodied Carbon)	Embodied carbon in materials, including emissions from the extraction of raw materials, manufacturing and transportation of materials and components for the construction of the WDA infrastructure, where applicable.
A4 (Transportation) A5 (Construction)	Marine vessels and helicopters associated with the construction of the WDA infrastructure, including transportation to the WDA and onsite operation such as installation processes in the WDA.
B1 (Use) B2 (Maintenance) B3 (Repair) B4 (Replacement)	Sulphur hexafluoride (SF_6) Marine vessels and helicopters
C1-C4 (Decommissioning)	End-of-Life activities

1.2.1 Embodied Emissions in Materials and Components

10. Embodied carbon in materials associated with the Wind Turbine Generators (WTGs) has been estimated using the emission factor obtained from the Environmental Product Declaration (EPD) for a 14 MW WTG (International EPD, 2024), outlined in **Table 1.3**. The EPD encompasses a full LCA and is considered to be representative of the 15 MW WTG proposed for the WDA. Therefore, the level of embodied carbon calculated for the WTGs includes emissions associated with materials production and manufacturing.

11. For the other WDA infrastructure (e.g., foundations and cables), there was no representative EPD or LCA data available. Therefore, embodied emissions in materials for these components have been quantified from 'Cradle-to-factory gate', which includes the extraction, manufacture and production of materials to the point at which they leave the final processing site. Emissions associated with energy used directly in the manufacturing of these components are not accounted for due to a lack of data availability at the time of assessment. However, emissions from energy consumption during the manufacturing of components are not considered to result in a change to the outcome of the significant of effect assessment presented in Section 19.7.2.1 of **Chapter 19 Greenhouse Gas Assessment**.

12. As outlined in **Section 1.1.2**, the GHG assessment is not a full LCA; therefore, simplifications are applied to the methodology. Nonetheless, the methodology remains robust and appropriate for an GHG assessment for EIA.

13. Emissions associated with the delivery of materials to the Study Area are quantified separately through the use of marine vessels, as detailed in **Section 1.2.2**. Road vehicles associated with the

delivery of materials to the port are excluded from the scope of this assessment due to a lack of data availability.

14. GHG emissions were calculated from quantities or volumes of known materials that would be used in construction, including the following WDA infrastructure:

- WTGs and associated fixed foundations and scour protection;
- Offshore Substation Platforms (OSPs) and associated fixed foundations and scour protection;
- Inter-array cables and associated cable protection;
- OSP link cables and associated cable protection; and
- The portion of the offshore export cable(s) located within the WDA, and associated cable protection.

15. Full details of the WDA infrastructure are provided in **Chapter 3 Project Description**.

16. To provide a precautionary assessment, it is assumed that there will be no reduction in the emission intensity during the abstraction and manufacturing of materials up until and during the construction phase of the WDA. This is considered to be a conservative approach as the earliest year of construction of the WDA is anticipated to be 2030, where the emissions intensity of some sectors, such as transport and industry, are likely to have reduced. The indicative maximum quantities of each type of construction material to be used on site were provided by the Applicant, and the relevant emission factors from the Inventory of Carbon and Energy (ICE) database (Circular Ecology and University of Bath, 2024), where possible. The ICE database provides a comprehensive database of emission factors for embodied carbon in materials that are commonly used in the UK, following the cradle-to-factory gate approach. Alternative sources for emission factors are used for more specific materials and components of offshore windfarms and are detailed **Table 1.3**.

Table 1.3 Emission factors in embodied GHGs in materials and components

Material	Emission Factor (kg CO_2e/kg, unless otherwise stated)	Source	Notes
Aluminium	6.67	ICE Database, v4.0 (Circular Ecology and University of Bath, 2024)	N/A
Cement Grout	0.62		N/A
Concrete	0.10		N/A
Copper	3.81		N/A
High-Density Polyethylene (HDPE) Pipe	2.52		N/A
Polypropylene	4.98		N/A
Steel (Average)	2.34		Average of embodied CO_2e steel values provided in the ICE database.
Rock or gravel	0.08		Stone (general)
XLPE (cross linked polyethylene)	1.93		N/A
Lead	1.67	Cableizer (n.d.)	N/A
Fibreglass	4.18	Proxy Emission Factor Database extracted from the Carbon Trust	N/A

Material	Emission Factor (kg CO_2e/kg, unless otherwise stated)	Source	Notes
		Offshore Wind (OSW)-Footprinting-Tool (Carbon Trust, 2024b)	
SF_6	23,5000	Department for Energy Security and Net Zero (DESNZ) 2025 UK Government GHG conversion Factors for Company Reporting (DESNZ, 2025)	N/A
Siemens Gamesa 14 MW WTG - full asset production	7,275,570 (as kgCO_2e/unit)	Proxy Emission Factor Database extracted from the Siemens SG 14-236 EPD (International EPD, 2024)	Emission factor is in units of CO_2e per WTG, which includes nacelle and internals, blades, hub, and rotor system

17. The assumed predominant material components of the OSP used in the GHG assessment include the following:

- Steel;
- HDPE;
- Fibreglass;
- Copper;
- Transformer Natural Ester Oil; and
- Switchgear – SF_6.

18. The quantity of embodied carbon in cables was calculated using indicative cable material contents provided by the Applicant, as outlined in **Table 1.4**.

Table 1.4 WDA cable material content

Material	Offshore export cable (WDA only)	Inter-Array Cable
	Content (kg per route m)	
Copper	45	20
XLPE	13	12
Lead	18	N/A
Steel	20	48
Other Polymer	4	25

19. Details surrounding embodied emissions in spare parts are not yet known at this stage. Therefore, an assumption of 3.7% of total whole lifecycle GHG emissions has been applied, as obtained from literature (Thomson and Harrison, 2015).

20. The use of WTG consumables (e.g. lubricants, fuel oil, nitrogen, glycol, and coolants) during the operation of the WDA infrastructure is acknowledged. However, emissions associated with

consumables have not been included in the GHG assessment due to the limited availability of detailed information at the time of the assessment. The emissions associated with WTG consumables are not expected to have a material impact on the overall GHG emissions of the WDA infrastructure, and the outcome of the significance of effect assessment presented in Section 19.7.2.1 of **Chapter 19 Greenhouse Gas Assessment**. Therefore, the GHG assessment remains robust and appropriate for inclusion in the EIA.

1.2.2 Marine Vessels

1.2.2.1 Activity Data

21. Marine vessels will be used to bring materials and components to the WDA, install the windfarm infrastructure (see **Chapter 3 Project Description**), and provide crew accommodation and support during construction (including pre-construction activities), operation and maintenance (O&M), and decommissioning.

22. Activity data for vessels, including movements and days on site during the construction (including pre-construction activities) and O&M phases[2] are outlined in **Table 1.5**, **Table 1.6** and **Table 1.7,** respectively. To assess a worst-case scenario, the assessment considers a maximum number of vessels and vessel movements to/from the WDA. As the final port locations have not yet been confirmed, for the GHG assessment the total distance from the port is assumed to be 400 km. The fabrication of components may also occur outside of the UK. It is anticipated that due to the size and volume of the proposed infrastructure, the overwhelming majority of components will be transported to the site by vessel as detailed in Section 3.6.10 of **Chapter 3 Project Description**. It should be noted that the vessel activities presented below are assumed to include requirements for the Offshore ECC.

Table 1.5 Indicative number of vessel movements during pre-construction

Activity	Vessel type	Maximum Number of Return Trips	Total Days on site per Vessel Type
Lifecycle Module(s): A0 (Pre-construction)			
Pre-construction	Site Investigation Survey (Geotechnical & Geophysical) Vessels)	40	360
	Support Vessels	40	360
	Unexploded Ordnance Clearance Survey Vessels	20	180
	Boulder clearance vessels	20	180
	Pre-Lay Grapnel Run (PLGR) vessels	20	180

[2] Specific activity data has not been estimated for vessels during decommissioning, as details surrounding decommissioning activities are not known at this stage.

Table 1.6 Indicative number of vessel movements during construction

Activity	Vessel type	Maximum Number of Return Trips	Total Days on site per Vessel Type*
Lifecycle Module(s): A4 (Transport to Site) and A5 (Construction)			
Foundation Installation	Dredging vessel	30	274.5
	Tugs and barges storage and transport	1100	274.5
	Jack-up vessel	300	274.5
	Dynamic Position Heavy Lift Vessel	525	274.5
	Support vessels	500	274.5
WTG Installation	Jack-up vessel	300	137.3
	Dynamic Position Heavy Lift Vessel	200	137.3
	Accommodation Vessel	40	137.3
	Windfarm service Vessel	30	137.3
	Support Vessels	400	137.3
OSP Installation	Installation Vessel	100	137.3
	Tug with accommodation barge	100	137.3
	Supply Vessel	50	137.3
Cable Installation	Support Vessels	500	137.3
	Inter-Array Cable Laying Vessel	107	274.5
	Accommodation Vessel	42	274.5
	Inter-Array Cable (IAC)-Installation Vessel (ISV)	32	274.5
	IAC- Trenching Support Vessel (TSV)	20	274.5
	IAC- Crew Transfer Vessel (CTV)	204	274.5
	IAC - Rock Fall Pipe Vessel	32	274.5
	IAC- Light Construction Vessel (LCV)	161	274.5
	Export Offshore Cable Laying Vessel	107	137.3
	Export Cable Nearshore Laying Vessel	50	137.3

Activity	Vessel type	Maximum Number of Return Trips	Total Days on site per Vessel Type*
	Export Cable Support Vessel	161	137.3
	Export Cable Pre-Trenching/Backfilling Vessel	43	137.3
	Export cable - cable jetting vessel - Controlled Flow Evacuation (CFE)	43	137.3
	Export Cable - Survey Vessel	161	137.3
	Export Cable - Multi Cat Vessel	139	137.3
	Export Cable - Rock Fall Pipe Vessel	32	137.3
	Workboat	190	549
* Values have been rounded to one decimal place where applicable.			

Table 1.7 Indicative number of vessel movements during operation and maintenance

Activity	Vessel type	Maximum Number of Return Trips (over 35 year operational life)	Total Days on site per Vessel Type
Lifecycle Module(s): B2-B4 (Operation and Maintenance)			
Operation and Maintenance	Service Operation Vessel (SOV)	1,680	11,760
	SOV Daughter Craft	N/A[3]	1,750
	CTV	12,600	6,300
	Jack Up Vessel	280	280
	Cable laying / maintenance vessels	35	4,140
	Geophysical survey vessels	210	18,900

1.2.2.2 Vessel Emissions Calculations

23. The methodology to calculate emissions from vessels is based on best practice guidance documents, including the United States Environmental Protection Agency's (US EPA) 'Port Emissions Inventory Guidance: Methodologies for Estimating Port-Related and Goods Movement Mobile Source

[3] Daughter crafts are transported on the SOV to the WDA, therefore they do not release GHG emissions during transit.

Emissions' (2022), and the Global Maritime Energy Efficiency Partnerships Project's (GloMEEP) 'Port Emissions Toolkit' (GloMEEP, 2018).

24. Emissions from marine vessels associated with the WDA were quantified based upon an estimation of fuel consumption, estimated from the activity data presented in **Section 1.2.2.1**. Emission factors for marine gas oil (MGO), in kg CO_2e per kWh are obtained from DESNZ (DESNZ, 2025), which is assumed to be the most common fuel used during the construction, and operational and maintenance phases. The shipping sector is expected to decarbonise over the lifespan of the WDA, although projections for the speed and the extent to which this will take place are difficult to predict. It is therefore assumed for the purposes of this assessment that marine vessels will continue to use MGO during the construction and O&M phases of the WDA. This approach is precautionary and likely to result in an overestimation of emissions.

25. Vessel emissions were calculated in accordance with the following formula:

$$E_{transit} = ((A \times PE \times LF_{prop}) + (A \times AE \times LF_{aux})) \times EF$$

Where:

$E_{transit}$ – *Emissions during transit (tonnes CO_2e)*

A – Activity (approximate hours engine in use)

PE – Propulsion engine size (kW)

AE – Auxiliary engine (kW)

LF_{prop} – *Load Factors for propulsion engines*

LF_{aux} – *Load Factors, for auxiliary engines*

EF – Emission Factor (tonnes CO_2e/kWh)

26. Vessel engine sizes were obtained from public vessel specification sheets, where available. Propulsion engine sizes were assumed to include the main engine and thrusters. However, auxiliary engine sizes tend to be undisclosed. Therefore, they were estimated based on the total installed power, less the propulsion engine size, or calculated using a ratio provided in US EPA's report on vessel emissions (US EPA, 2009). The majority of vessels included in the GHG assessment could be categorised as bulk carriers, whose auxiliary to propulsion ratio is estimated at 0.222. For vessels without total installed power specified and whose type falls outside of the US EPA's ratio table, an indicative estimate of 10% of the propulsion engine size was assumed for the auxiliary engine (US EPA, 2009).

27. Emissions were calculated separately for two different modes of activity, in transit and whilst situated within the WDA for offshore construction purposes, due to different engine loads factors for vessels during these periods. The activity hours for each transit were calculated by dividing the total distance covered by the average transit speed. The estimated number of days each vessel will spend on site was provided by the Applicant.

28. Vessels have various operating modes such as cruising, manoeuvring and hotelling, which affect how much work is being undertaken by the propulsion and auxiliary engines. In emission calculations, this is captured by the load factor, which represents the percentage of a vessel's maximum engine load while undertaking a specific activity. A vessel's engines are rarely operated at 100% or more of its maximum load due to fuel consumption costs, efficiency and engine maintenance requirements, therefore most vessel operators limit their engine load to around 83% or less (GloMEEP, 2018).

29. During transit, load factors will be higher for propulsion than auxiliary engines, and vice versa for offshore construction activities. Load factors for propulsion engines for vessels in transit were derived from previous project experience, and the GloMEEP guidance for those undertaking offshore construction activities. Load factors for auxiliary engines were obtained from US EPA guidance. Load factors used in the vessel emission calculations are detailed in **Table 1.8**.

Table 1.8 Assumed engine load factors

Engine Type	Activity	Load factor	Data Source	Assumptions
Propulsion engine	In transit	0.75	Assumed based on typical load factors	Vessels assumed to be in cruising mode.
	Offshore construction	0.31 (tugs) 0.38 (work boats and miscellaneous)	GloMEEP (2018)	Vessels assumed to be in manoeuvring mode as worst-case scenario.
Auxiliary engine	0.38 (work boats and miscellaneous)	0.17	US EPA (2009)	Vessels assumed to be in cruising mode.
	In transit	0.26		All vessels assumed to be bulk carriers, tugs or miscellaneous vessels.

1.2.3 Helicopters

30. Helicopter movements associated with the O&M phase of the WDA will result in the release of GHG emissions. Helicopters may transfer technicians to turbines during commissioning of the WDA, and to carry out maintenance tasks during the O&M phase. The volume of GHG emissions from helicopter use during the operation and maintenance phases is calculated by determining the expected fuel consumption using trip data.

31. The anticipated number of helicopter journeys during the O&M phase are outlined in **Table 1.9**. No helicopter movements are anticipated during the construction phase of the WDA.

Table 1.9 Indicative operation and maintenance phase helicopter movements

Lifecycle Module	Phase	Assumed distance to Helicopter Base (km)	Total Number of Return Trips (over the 35 year operational life)
B2-B4 (operation and maintenance)	In transit	140	576

32. The total distance travelled by helicopters is determined by multiplying the number of trips by the maximum trip distance. The maximum helicopter trip distance is approximately 140 km.

33. The type of helicopter assumed for the assessment is the Leonardo AW139, which has an average fuel consumption rate of 430 kg/h, and a maximum cruise speed of 306 km/h. Emission factors for aviation turbine fuel (or jet fuel), in CO_2e/tonnes fuel, are obtained from the DESNZ (DESNZ, 2025).

1.2.4 Fugitive Emissions

34. SF_6 is commonly used as an insulating and circuit-breaking gas in the operation of high-voltage switchgears and other electrical equipment, which are required as part of both the Project's offshore

and onshore infrastructure. SF_6 is an extremely potent GHG, with a global warming potential of 24,300, as determined by the Intergovernmental Panel on Climate Change (IPCC) in the Sixth Assessment Report (AR6). This means that every kilogram (kg) of SF_6 leaked to atmosphere has the equivalent effect on global warming as the emission of 24.3 tonnes of CO_2e.

35. The methodology to calculate GHG emissions from SF_6 is based on an assumed annual leakage rate applied against the stock contained in electrical equipment. The worst-case leakage rate is assumed to be 0.5% per year. This value is obtained from IEC 62271-203 (IEC, 2022), which is a standard which specifies that the maximum permissible leakage rate for gas insulated metal enclosed switchgear is 0.5% of the total gas content per year. While this figure is likely conservative, particularly for newer equipment that may achieve lower leakage rates, it is considered appropriate for use as a worst-case scenario.

36. The resulting total emissions over the life of the WDA were calculated in accordance with the following formula:

$$E_{SF6} = S * LR * GWP * L$$

Where:

E_{SF6} – Emissions over the lifetime of the WDA (tonnes CO_2e)

S – Stock of SF_6 contained in electrical equipment (kg)

LR – Assumed annual leakage rate (% per year)

GWP – Global Warming Potential of SF_6 (24.3 (tonnes CO_2e/kg))

L – Lifetime of the WDA (years)

37. While SF_6 has historically been widely used in switchgear equipment, there is a growing industry trend and regulatory drive towards adopting SF_6-free alternatives. For the purposes of the EIA a worst-case scenario has been assumed based on the use of SF_6-containing equipment to ensure a precautionary approach. This allows for a comprehensive assessment of potential environmental impacts, while maintaining flexibility for future design improvements aligned with best environmental practices.

1.2.5 Decommissioning

38. Details surrounding decommissioning activities and downstream end-of-life processes are not yet known at this stage of the Project. Section 3.3.15 of **Chapter 3 Project Description** provides further details on the activities anticipated to take place during the decommissioning phase. This includes the proposed removal of all structures above the seabed (except for scour protection and cable protection) and the removal of all offshore cables. This forms the basis for the worst-case scenario for the assessment of the GHG emissions released during the decommissioning phase, as detailed in Table 19.5 of the **Chapter 19 Greenhouse Gas Assessment**.

39. The worst-case scenario assumes that decommissioning emissions are equivalent to the construction phase emissions from transportation and construction activities by marine vessels. While future end-of-life capabilities are expected to enable greater reuse, repurposing, and recycling of recovered materials and components, current limitations suggest that some materials and components may be sent to landfill. Given these current limitations, a conservative approach has therefore been applied to quantify emissions from materials and components, with landfill disposal assumed where improved recovery routes cannot presently be assured.

40. The potential for materials and components from the WDA infrastructure to be reused, recycled or repurposed falls under lifecycle module D1 (reuse, recycling, energy recovery and other recovery). As detailed in Section 19.5.2.2.1 of **Chapter 19 Greenhouse Gas Assessment**, this module is not

considered in the GHG assessment as it is outside the system boundary for the WDA Infrastructure. Additionally, there is uncertainty regarding the final end-of-life processing methods at the time of the assessment.

41. Consequently, the GHG emissions sources during decommissioning, which are detailed in Table 19.10 of **Chapter 19 Greenhouse Gas Assessment**, include lifecycle module C1, C2, C3 and C4. C1, C2 and C3 emissions are assumed to be equivalent to the construction lifecycle modules, A4 and A5. While the emissions for C4 are calculated using the assumed proportion of WTG, OSP and cable materials sent to landfill, based on the indicative material quantities provided by the Applicant. The total quantities of materials to landfill are multiplied by the appropriate landfill disposal emission factor obtained from the DESNZ UK Government GHG Conversion Factor 2025 (DESNZ, 2025). **Table 1.10** presents the quantity of each material assumed to be sent to landfill per component, and the associated emission factor.

42. The EPD for WTGs, representative of those used in the WDA, referenced in **Section 1.2.1**, details the end-of-life hypothesis for inter-array cables and export cables, which states that typically 5% of these components are sent to landfill. Additionally, as stated in Section 19.7.2.3 of **Chapter 19 Greenhouse Gas Assessment**, current estimates for wind turbine recyclability range from 85% to 90% (Schmid et al., 2020). Therefore, for the GHG assessment, 5% of the anticipated total material quantities associated with the WDA cables are assumed to be sent to landfill. Similarly, 10% of the anticipated total material quantities associated with the WTGs and OSPs are assumed to be sent to landfill.

Table 1.10 Decommissioning phase landfill material quantities and emission factors

Component	Material	Quantity to Landfill (tonnes)	Waste Type (GHG conversion factor 2025)	Emission Factor (kg CO_2e/tonnes)
WTG	Aluminium	165	Metal: scrap metal	8.98
WTG	Copper	336	Metal: scrap metal	8.98
WTG	Tin	0.06	Metal: scrap metal	8.98
WTG	Zinc	2.1	Metal: scrap metal	8.98
WTG	Balsa	236	Wood	925
WTG	Carbon Fibre	178	Commercial and industrial waste	521
WTG	Fibre glass	2,086	Commercial and industrial waste	521
WTG	Glass reinforced plastic	46.1	Commercial and industrial waste	521
WTG	Graphite	1.4	Commercial and industrial waste	521
WTG	Battery/high-tech metals	0.72	Batteries	8.98
WTG	Steel and Iron	14,498	Metal: scrap metal	8.98
WTG	Alloying Elements/Speciality Metals	459	Metal: scrap metal	8.98

Component	Material	Quantity to Landfill (tonnes)	Waste Type (GHG conversion factor 2025)	Emission Factor (kg CO_2e/tonnes)
WTG	Rare Earth Metals	33.6	Metal: scrap metal	8.98
WTG	Epoxy	418	Commercial and industrial waste	521
WTG	Polyethylene terephthalate (PET) foam	0.96	Plastics: PET (incl. forming)	8.98
WTG	Plastic	12.6	Plastics: average plastics	8.98
WTG	polyester	436	Plastics: PET (incl. forming)	8.98
WTG	Polyvinyl Chloride (PVC) foam	90.6	Plastics: PVC (incl. forming)	8.98
WTG	Silicone	4.2	Commercial and industrial waste	521
WTG	Thermoplastic	114	Plastics: average plastics	8.98
WTG	Other	201	Commercial and industrial waste	521
OSP	Steel	309	Metal: scrap metal	8.98
OSP	Stainless steel	3,733	Metal: scrap metal	8.98
OSP	HDPE	190	Plastics: HDPE (incl. forming)	8.98
OSP	Fiberglass	38.7	Commercial and industrial waste	521
OSP	Copper	309	Metal: scrap metal	8.98
OSP	Transformers - Insulating liquid, Midel 7131	89.2	Commercial and industrial waste	521
OSP	Switchgear - SF6	4.1	Commercial and industrial waste	521
Cables - Inter-array cables	Copper	11,440	Metal: scrap metal	8.98
Cables - Inter-array cables	XLPE	6,864	Plastics: average plastics	8.98
Cables - Inter-array cables	Armouring (steel)	27,456	Metal: scrap metal	8.98
Cables - Inter-array cables	Other polymer	14,300	Plastics: average plastics	8.98
Cables - Offshore export cables (WDA only)	Copper	450	Metal: scrap metal	8.98

Component	Material	Quantity to Landfill (tonnes)	Waste Type (GHG conversion factor 2025)	Emission Factor (kg CO_2e/tonnes)
Cables - Offshore export cables (WDA only)	XLPE	130	Plastics: average plastics	8.98
Cables - Offshore export cables (WDA only)	Lead	180	Commercial and industrial waste	521
Cables - Offshore export cables (WDA only)	Armouring (steel)	200	Metal: scrap metal	8.98
Cables - Offshore export cables (WDA only)	Other polymer	40	Plastics: average plastics	8.98
Cables - OSP Link Cables	Copper	612	Metal: scrap metal	8.98
Cables - OSP Link Cables	XLPE	177	Plastics: average plastics	8.98
Cables - OSP Link Cables	Lead	245	Commercial and industrial waste	521
Cables - OSP Link Cables	Armouring (steel)	272	Metal: scrap metal	8.98
Cables - OSP Link Cables	Other polymer	54.4	Plastics: average plastics	8.98

1.3 WHOLE PROJECT GHG ASSESSMENT METHODOLOGY

43. To fully consider the impact on net GHG emissions as a result of the implementation of the Project, consideration of the combined emissions from the offshore and onshore infrastructure ("whole Project") is also required. However, as the transmission infrastructure is subject to separate EIA applications, the whole Project assessment has been undertaken using indicative information and estimates of the emission sources associated with the transmission infrastructure that were available at the time of writing the GHG chapter. A whole Project assessment is undertaken using the calculated GHG emissions for the WDA infrastructure combined with the indicative emissions associated with the transmission infrastructure (i.e. the Offshore ECC and the OnTDA), and the overall effect significance is evaluated. As the EIA applications for the Offshore ECC and OnTDA progress and additional information becomes available, this whole Project assessment will be updated with more recent and accurate information in the applications for the Offshore ECC and the OnTDA.

44. For the purposes of the assessment, the Offshore ECC export cable(s) is anticipated to be 800 km in length, while the OnTDA cable corridor 2.6 km. The embodied carbon in materials for the Offshore ECC export cable and OnTDA cable corridor was derived using the methodology outlined in **Section 1.2.1** and indicative cable material contents provided by the Applicant as presented in **Table 1.11**. The outputs of these calculations are combined with the total WDA GHG emissions to provide an indicative whole Project GHG emissions.

Table 1.11 Offshore ECC and onshore export cable material content

Material	Offshore export cable (Offshore ECC)	Onshore export cable
	Content (kg per route m)	
Copper	45	45
XLPE	13	13
Lead	18	N/A
Steel	20	N/A
Other Polymer	4	4

REFERENCES

Arvesen, A., Hertwich, E. G. (2012). Corrigendum: Environmental implications of large-scale adoption of wind power: a scenario-based life cycle assessment. Environmental Research Letters. 7(3), p.039501.

Bhandari, R., Kumar, B., Mayer. F, (2020). Life cycle greenhouse gas emission from wind farms in reference to turbine sizes and capacity factors, Journal of Cleaner Production, Volume 277, 123385

Bonou, A., Laurent, A., Olsen, S. I. (2016). Life cycle assessment of onshore and offshore wind energy-from theory to application. Applied Energy, Volume 180, pp. 327-337.

Cableizer (n.d.). Embodied energy and carbon. Available at: https://www.cableizer.com/documentation/EEC/. [Accessed 01 October 2025].

Circular Ecology and University of Bath (2024). Inventory of Carbon and Energy (ICE) Database v4.0. Available at: https://circularecology.com/embodied-carbon-footprint-database.html [Accessed 01 October 2025].

Chen, G. Q., Yang, Q., Zhai, Y. H. (2011). Renewability of wind power in China: A case study of non-renewable energy cost and greenhouse gas emission by a plant in Guangxi. Renewable and Sustainable Energy Review, Volume 15, Issue 5, pp. 2322-2329.

Climate Change Committee (2024). Progress in reducing emission 2024 Report to Parliament. Available online at: https://www.theccc.org.uk/wp-content/uploads/2024/07/Progress-in-reducing-emissions-2024-Report-to-Parliament-Web.pdf [Accessed 01 October 2025].

Climatiq (2025). Emission Factor Graphite. Available at: https://www.climatiq.io/data/emission-factor/ccf035d9-78fa-44d6-bb5e-d9371e9c8cb5 [Accessed 01 October 2025].

Department for Business, Energy and Industrial Strategy (BEIS) (2017). The Clean Growth Strategy : Leading the way to a low carbon future. Available at: https://assets.publishing.service.gov.uk/media/5ad5f11ded915d32a3a70c03/clean-growth-strategy-correction-april-2018.pdf [Accessed 08 October 2025].

Department for Business, Energy and Industrial Strategy (BEIS) (2019). Industrial Strategy: Offshore Wind Sector Deal. Available at: https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution [Accessed 8 October 2025].

Department of Energy, Security and Net Zero (DESNZ) (2025). Greenhouse gas reporting: conversion factors 2025. Available at: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2025 [Accessed 08 October 2025].

Dolan, S. L., & Heath, G. A. (2012). Life cycle greenhouse gas emissions of utility-scale wind power: systematic review and harmonization. Journal of Industrial Ecology, 16, S136-S154

GloMEEP (2018). Port Emissions Toolkit: Guide No.1 Assessment of Port Emissions.

Harrison, G.P., Maclean, E. (Ned). J., Karamanlis, S. and Ochoa, L.F. (2010). Life cycle assessment of the transmission network in Great Britain. Energy Policy, 38(7), pp.3622–3631. doi: https://doi.org/10.1016/j.enpol.2010.02.039. [Accessed 08 October 2025].

Hill, C. & Norton, A. (2018). LCA database of environmental impacts to inform material selection process. Available at: https://www.sintef.no/globalassets/project/dacomat/dacomat-deliverable-6.1.pdf/ [Accessed 08 October 2025].

HM Government (2020). Ten Point Plan for a Green Industrial Revolution. Available at: https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution [Accessed 10 October 2025].

HM Government (2021). Net Zero Strategy: Build Back Greener. Available at: https://assets.publishing.service.gov.uk/media/6424b2d760a35e000c0cb135/carbon-budget-delivery-plan.pdf [Accessed 08 October 2025].

HM Government (2022). British Energy Security Strategy. Available at: https://www.gov.uk/government/publications/british-energy-security-strategy/british-energy-security-strategy#renewables [Accessed 08 October 2025].

Hongyue, J., et al. (2016). Comparative Life Cycle Assessment of NdFeB Magnets: Virgin Production versus Magnet-to-Magnet Recycling. Available at: https://www.sciencedirect.com/science/article/pii/S2212827116006508/pdf?md5=813d106b035ecf4f19168f91347b7fee&pid=1-s2.0-S2212827116006508-main.pdf and https://eurometaux.eu/media/jmxf2qm0/metals-for-clean-energy.pdf [Accessed 08 October 2025].

Institute of Environmental Management and Assessment (IEMA) (2022). Institute of Environmental Management and Assessment (IEMA) Guide: Assessing Greenhouse Gas Emissions and Evaluating their Significance. Available at: https://www.iema.net/media/xmgpoopk/2022_iema_greenhouse_gas_guidance_eia.pdf [Accessed 08 October 2025].

International Electrotechnical Commission (IEC) (2022). IEC 62271-203:2022. High-voltage switchgear and control gear – Part 203: AC gas-insulated metal-enclosed switchgear for rated voltages above 52 kV. International Electrotechnical Commission. Available at: https://webstore.iec.ch/en/publication/65853 [Accessed 08 October 2025].

International Energy Agency (IEA) (2021a), GHG emissions intensity for class 1 nickel by resource type and processing route, IEA, Paris Available at; https://www.iea.org/data-and-statistics/charts/ghg-emissions-intensity-for-class-1-nickel-by-resource-type-and-processing-route [Accessed 02 October 2025].

International Environmental Product Declaration (EPD) System (2024). Electricity from a European offshore wind farm using SG 14-236 wind turbines. Available at: https://www.environdec.com/library/epd9792 [Accessed 02 February 2026].

IEA (2021b), GHG emissions intensity for lithium by resource type and processing route, IEA, Paris Available at: https://www.iea.org/data-and-statistics/charts/ghg-emissions-intensity-for-lithium-by-resource-type-and-processing-route [Accessed 02 October 2025].

Lam, K., Bioindustrial, C. and Pacific, A. (2022). A Tale of Two Esters - Why the Natural One is the Better Dielectric Fluid A Tale of Two Esters -Why the Natural One is the Better Dielectric Fluid. Available at: https://www.cargill.com/doc/1432242852210/a-tale-of-two-esters-why-the-natural-one-is-better.pdf [Accessed 08 October 2025].

Schmid, M., Ramon, N.G., Dierckx, A., Wegman, T. (2020) Accelerating Wind Turbine Blade Circularity. Available at: https://windeurope.org/wp-content/uploads/files/about-wind/reports/WindEurope-Accelerating-wind-turbine-blade-circularity.pdf [Accessed 10 October 2025].

Scottish Government (2020a). Offshore wind policy statement. Available at: https://www.gov.scot/publications/offshore-wind-policy-statement/ [Accessed 10 October 2025].

Scottish Government (2020b). Sectoral Marine Plan for Offshore Wind Energy. Available at: https://www.gov.scot/binaries/content/documents/govscot/publications/strategy-plan/2020/10/sectoral-marine-plan-offshore-wind-energy/documents/sectoral-marine-plan-offshore-wind-energy/sectoral-marine-plan-offshore-wind-energy/govscot%3Adocument/sectoral-marine-plan-offshore-wind-energy.pdf [Accessed 10 October 2025].

Scottish Government (2024). Scottish Energy Statistics Hub. Available at: https://scotland.shinyapps.io/sg-scottish-energy-statistics/?Section=RenLowCarbon&Subsection=RenElec&Chart=RenElecSources [Accessed 08 October 2025].

Siemens Gamesa (n.d.). Environmental Product Declaration SG 8.0-167 DD. Available from: https://www.siemensgamesa.com/global/en/home.html#:~:text=Environmental%20Product%20Declaration%20SG%208.0-167%20DD%20Assessing%20the,power%20plant%20The%20environmental%20impact%20of%20wind%20power [Accessed 11 November 2024].

Spyroudi, A. (2021). Carbon footprint of offshore wind farm components. Available at: https://ore.catapult.org.uk/wp-content/uploads/2021/04/Carbon-footprint-of-offshore-wind-farm-components_FINAL_AS-3.pdf. [Accessed 11 November 2024].

National Renewable Energy Laboratory (NREL) (2015). Cost of Wind Energy Review. Available at: https://www.nrel.gov/docs/fy17osti/66861.pdf [Accessed 01 October 2024].

The Carbon Trust (2024a). Offshore Wind Industry Product Carbon Footprinting Guidance. Available at: https://www.carbontrust.com/our-work-and-impact/guides-reports-and-tools/standardising-offshore-wind-carbon-footprinting [Accessed 07 October 2025].

The Carbon Trust (2024b). Offshore Wind Industry Product Carbon Footprinting Tool. Available at: https://view.officeapps.live.com/op/view.aspx?src=https%3A%2F%2Fctprodstorageaccountp.blob.core.windows.net%2Fprod-drupal-files%2Fdocuments%2Fresource%2Fpublic%2FOSW-Footprinting-Tool.xlsm&wdOrigin=BROWSELINK [Accessed 07 October 2024].

Thomson, R. C., Harrison, G. P. (2015). Life Cycle Costs and Carbon Emissions of Offshore Wind Power. Available at: https://www.pure.ed.ac.uk/ws/portalfiles/portal/19730442/Main_Report_Life_Cycle_Costs_and_Carbon_Emissions_of_Offshore_Wind_Power.pdf [Accessed 08 October 2025].

US EPA (2022). Port Emissions Inventory Guidance: Methodologies for Estimating Port-Related and Goods Movement Mobile Source Emissions. Available at: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1014J1S.pdf [Accessed 11 November 2024].

US EPA (2009). Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories: Final Report. Available at: https://www.epa.gov/sites/default/files/2016-06/documents/2009-port-inventory-guidance.pdf [Accessed 11 November 2024].

Yang, J., Chang, Y., Zhang, L., Hao, Y., Yan, Q., & Wang, C. (2018). The life-cycle energy and environmental emissions of a typical offshore wind farm in China. Journal of Cleaner Production, 180, 316-324.