MONA OFFSHORE WIND PROJECT

Preliminary Environmental Information Report

Volume 8, annex 28.1: Greenhouse Gas Assessment

Image of an offshore wind farm

April 2023
Final

Document status

Version	Purpose of document	Authored by	Reviewed by	Approved by	Review date
Rev01	Draft for Client review	RPS	bp/EnBW		13/09/22
Rev02	Addressing client comments	RPS	bp/EnBW		07/11/22
Rev03	Addressing client comments	RPS	bp/EnBW		23/01/2023
Rev04	Final	RPS	bp/EnBW	bp/EnBW	10/03/2023

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Acronyms

Acronym	Description
ALC	Agricultural Land Classification
BECCS	Bioenergy with Carbon Capture Storage
CCC	Climate Change Committee
CSP	Concentrating solar panels
CTVs	Crew Transfer Vessels
DUKES	Digest of UK Energy Statistics
EPD	Environmental Product Declaration
FES	Future Energy Scenario
GHG	Greenhouse Gas
GWP	Global Warming Potential
HGV	Heavy Goods Vehicles
HVAC	High Voltage Alternating Current
IEA	International Energy Agency
IPPC	Intergovernmental Panel on Climate Change
LCA	Life Cycle Assessment
NREL	National Renewable Energy Laboratory
PEIR	Preliminary Environmental Information Report
PD	Project Description
UNFCCC	United Nations Framework Convention on Climate Change

Units

Unit	Description
CO2e	Carbon dioxide equivalent
GW	Gigawatts
km	Kilometres
kg	Kilograms
MW	Megawatts
MWh	Megawatt Hours
MVA	Megavolt amperes
g	Grams
t	Tonnes

Definitions

Term	Definition
Future grid average	Projection of how clean the future UK Grid electricity is likely to be based on current policies. It refers to how many grams of carbon dioxide (CO_2) are released to produce a kilowatt hour (kWh) of electricity.
Life Cycle Assessment	The systematic analysis of the potential environmental impacts of products or services during their entire life cycle
Marginal generation source	Accounts for sustained changes in energy consumption and generation sources for the purposes of cost-benefit analysis, including policy appraisal.
UK Grid Carbon Intensity	Carbon intensity is a measure of how clean UK Grid electricity is. It refers to how many grams of carbon dioxide (CO_2) are released to produce a kilowatt hour (kWh) of electricity.

1 GREENHOUSE GAS ASSESSMENT

1.1 Introduction

1.1.1.1 This Greenhouse Gas (GHG) technical report sets out the methodology and calculations of the GHG emissions for the Mona Offshore Wind Project. These calculations inform the assessment of the climate change impacts in volume 8, chapter 28: Climate change of the Preliminary Environmental Information Report (PEIR). This Annex should be read in conjunction with the chapter as supporting information.

1.1.1.2 GHG emissions have been estimated by applying published emissions factors to activities in the baseline and to those required for the Mona Offshore Wind Project. The emissions factors relate to a given level of activity, or amount of fuel, energy or materials used, to the mass of GHGs released as a consequence. This annex presents the technical calculations which relate to the potential magnitude of impact as assessed within the climate change chapter (volume 4, chapter 28: Climate change) of the PEIR.

1.2 Scope

1.2.1.1 The GHGs considered in this assessment are those in the 'Kyoto basket' of global warming gases expressed as their CO_2-equivalent (CO_2e) global warming potential (GWP). This is denoted by CO_2e units in emissions factors and calculation results. GWPs used are typically the 100-year factors in the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (IPCC, 2013) or as otherwise defined for national reporting under the United Nations Framework Convention on Climate Change (UNFCCC).

1.2.1.2 The annex scope considers the generation and transmission elements of the Mona Offshore Wind Project during the construction, operation and maintenance, and decommissioning phases. Key emissions sources included in the assessment are:

- onshore and offshore land use change
- embodied carbon emissions in materials for both generation and transmission assets
- transport emissions both onshore and offshore
- avoided emissions associated with the abatement of required fossil fuel generators and their associated emissions related with the UK electricity grid.

1.3 Methodology

1.3.1.1 Published benchmarks and representative project examples have been used to establish the baseline of current and future grid-average carbon intensity. Baseline information for this, as well as other relevant activities for the Mona Offshore Wind Project have been informed via the following source:

- BEIS (2023) Valuation of Energy Use and Greenhouse Gas: Supplementary guidance to the HM Treasury Green Book.

1.3.1.2 GHG emissions caused by an activity are often categorised into 'scope 1', 'scope 2' or 'scope 3' emissions, following the guidance of the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD) Greenhouse Gas Protocol suite of guidance documents (WRI and WBSCD, 2004).

- Scope 1 emissions: direct GHG emissions from sources owned or controlled by the company, e.g. from combustion of fuel at an installation.
- Scope 2 emissions: caused indirectly by consumption of purchased energy, e.g. from generating electricity supplied through the national grid to an installation.
- Scope 3 emissions: all other indirect emissions occurring as a consequence of the activities of the company, e.g. in the upstream extraction, processing and transport of materials consumed or the use of sold products or services

1.3.1.3 This assessment has sought to include emissions from all three scopes, where this is material and reasonably possible from the information and emissions factors available, to capture the impacts attributable most completely to the Mona Offshore Wind Project. These emissions shall not be separated out by defined scopes (Scopes 1, 2 or 3) in the assessment.

1.3.1.4 Due to the nature of the Mona Offshore Wind Project, i.e. exporting generated electricity to the grid, its gross GHG emissions total is dominated by avoided emissions. The avoided emissions are those that would have occurred as a result of the predicted UK Grid carbon intensity without the Project.

1.3.1.5 Emissions resulting from the manufacturing and construction of the wind turbines, cabling, onshore substation and associated site infrastructure (onshore and offshore) have been calculated via published benchmark carbon intensities and published lifecycle analysis (LCA) literature. Key sources relied upon for the assessment are as follows:

- Life Cycle Assessment Harmonization Project (NREL, 2013)
- Life Cycle Greenhouse Gas Emissions of Utility-Scale Wind Power (Dolan and Heath, 2012)
- Environmental Product Declaration Power transformer TrafoStar 500 MVA (ABB, 2003)
- RICS Professional Information, UK Methodology to calculate embodied carbon of materials RICS (2012).

1.3.1.6 The assessment has considered: (a) the GHG emissions arising from the Mona Offshore Wind Project, (b) any GHG emissions that it displaces or are avoided, compared to the current or future baseline, and hence (c) the net impact on climate change due to these changes in GHG emissions overall.

1.3.1.7 Consideration of GHG emissions over the lifetime of the Mona Offshore Wind Project is required in order to quantify its net contribution to climate change and as such the magnitude of change owing to the Mona Offshore Wind Project.

1.3.2 Embodied carbon

1.3.2.1 A life cycle assessment (LCA) comprises an evaluation of the inputs, outputs and potential environmental impacts that occur throughout the lifecycle of a particular project, in this case an offshore wind farm, encompassing either a cradle-to-gate (Project site) or a cradle-to-grave (accounting for in use and decommissioning) approach. This can be further broken down into the following LCA phases of development:

- materials and construction (A1-A5)
- operation and maintenance (B1-B5)
- decommissioning (C1-C4)

1.3.2.2 As the Mona Offshore Wind Project is currently in its early stages of design, data relating to specific metrics for site specific design details including chosen manufacturer of wind turbines, substation design etc. is currently unavailable. Therefore, data has been extracted from peer reviewed reports and UK Government bodies to provide estimate baseline figures for each stage of this LCA.

1.3.2.3 The current literature surrounding LCAs for wind turbines (both onshore and offshore) is characterised by a high degree of variability in the published GHG figures and therefore, a high degree of uncertainty occurs in selecting any one of these figures as a means of analysing the embodied GHGs in constructing a wind turbine or wind farm. As a means of dealing with this uncertainty, the primary source of emissions factors used in assessing the embodied carbon effects of the Mona Offshore Wind Project was a study by the National Renewable Energy Laboratory (NREL, 2013) Life Cycle Assessment Harmonization Project. and Dolan & Heath (2012).

1.3.2.4 The NREL (2013) study was based on the output of the Dolan & Heath (2012) paper and as such the Dolan & Heath has been referenced hereafter. This study (Dolan & Heath, 2012) analysed 126 distinct life cycle GHG emission assessments for both onshore and offshore wind power systems. However, these were from a small sample size of 49 different studies. The LCA Harmonization project conducted an exhaustive literature search, extracting normalized life cycle GHG emission estimates from published LCA literature. Data was screened to select only those references that met stringent quality and relevance criteria.

1.3.2.5 The report (Dolan & Heath, 2012) identified the median estimates of GHG emissions intensity figures for both onshore and offshore wind across the whole life-cycle, as being 11 gCO_2e/kWh. The NREL (2013) study further broke down and detailed the separation of intensity across the following life cycle stages relevant to this assessment:

- upstream including raw materials extraction, module manufacture, parts manufacture, wind farm construction (construction stage)
- operational stage including power generation, plant operation and maintenance
- downstream (decommissioning stage).

1.3.2.6 These estimated percentages have been applied to the Dolan & Heath intensity and are shown in Table 1.1. These intensity metrics are used in this assessment to calculate the embodied carbon for each stage of the LCA.

1.3.2.7 Given the early stage of the onshore substation design, there is some uncertainty regarding quantities of materials and in the grouping of the main categories of material. As a result, published benchmarks from RICS (2012) have been used to estimate possible emissions from the substation buildings materials and construction.

Table 1.1: Normalised lifecycle GHG emission estimates.

LCA Stage	Intensity	Unit
Upstream (A1-A5)	9.46	kg CO_2e /MWh
Ongoing (B1-B5)	0.99	kg CO_2e /MWh
Decommissioning (C1-C4)	0.55	kg CO_2e /MWh

1.3.2.8 There is limited design data and few published LCAs from which to calculate the embodied emissions associated with the substation, etc. Data from an environmental product declaration (EPD) for a 16 kVA – 1000 MVA transformer (ABB, 2003) has therefore, been used to provide an approximation of the potential order of magnitude of emissions, as transformers are among the major substation plant components and have a relatively high materials and carbon intensity, including the copper or aluminium winding.

1.3.3 Land use change

1.3.3.1 The calculation of climate change effects as a result of land use change considers the impact of the project on carbon sinks that may be required for temporary and permanent land take.

1.3.4 Operational avoided emissions

1.3.4.1 The assessment also considers the GHG emissions that would not be generated (i.e. avoided) during the operation of the Mona Offshore Wind Project during the future baseline (see section 1.5.2).

1.4 Assumptions and Limitations

1.4.1.1 The majority of the construction-stage GHG emissions associated with the manufacturing of components are likely to occur outside the territorial boundary of the UK and hence outside the scope of the UK's national carbon budget, policy and governance. However, in recognition of the climate change effect of GHG emissions (wherever occurring), and the need to avoid 'carbon leakage' overseas when reducing UK emissions, emissions associated with the construction stage have been presented within the assessment and quantification of GHG emissions as part of the Mona Offshore Wind Project.

1.4.1.2 Principal sources relied upon for the quantification of GHG emissions for the Mona Offshore Wind Project date back to 2012 (Dolan & Heath, 2012 and RICS, 2012). It is acknowledged that the design and equipment available in the present day compared with pre-2012 is significantly different. Nevertheless, the pre-2012 benchmarks represent a conservative (worst case) assumption concerning GHG emissions for the purposes of the assessment.

1.4.1.3 There is uncertainty about future climate and energy policy and market responses, which affect the likely future carbon intensity of energy supplies, and thereby the future carbon intensity of the electricity generation being displaced by the Mona Offshore

Wind Project. Government projections consistent with national carbon budget commitments have been used in the assessment.

1.4.1.4 The specific turbine technology and design of associated infrastructure (including substations etc.) that would be used by the Mona Offshore Wind Project have not yet been specified. Thus, there is a degree of uncertainty regarding all the project stage GHG emissions resulting from the manufacturing and construction of turbines and infrastructure. We have sought to limit the impact this might have by utilising peer reviewed published data representing a range with regards to emission intensity to present a conservative position concerning magnitude of GHG impact.

1.5 Baseline Environment

1.5.1 Current baseline

1.5.1.1 The current baseline for the onshore elements primarily comprises agricultural land. This land has been identified as Grades 3a and 3b (within volume 7, annex 20.1: Agricultural land classification published data of the PEIR), however, this land does not have high soil or vegetation carbon stocks (e.g. peat) that would be subject to disturbance by construction.

1.5.1.2 When considering the current baseline for the offshore elements the baseline consists of various subtidal habitats of stony reef, subtidal course, mixed sediments and diverse benthic communities.

1.5.1.3 With regards to the current baseline concerning the UK electricity grid at the time of writing, the conversion factor for company reporting UK Electricity generation carbon intensity resides at 239.63 kg CO_2e/MWh (including scope 3 but as generated, i.e. excluding transmission and distribution losses) (BEIS and Defra, 2022).

1.5.2 Future baseline

1.5.2.1 The future baseline GHG emissions for existing land-use without the Mona Offshore Wind Project are expected to remain similar to the current baseline.

1.5.2.2 The future baseline for electricity generation that would be displaced by the Mona Offshore Wind Project depends broadly on future energy and climate policy in the UK, and more specifically (with regards to day-to-day emissions) on the demand for the operation of the Mona Offshore Wind Project, compared to other generation sources available; this will be influenced by commercial factors and National Grid's needs.

1.5.2.3 The carbon intensity of baseline electricity generation is projected to reduce over time and so too would the intensity of the marginal generation source, displaced at a given time.

1.5.2.4 BEIS publishes projections of the carbon intensity of long-run marginal electricity generation and supply that would be affected by small (on a national scale) sustained changes in generation or demand (BEIS, 2023). BEIS's projections over the operating lifetime of the Mona Offshore Wind Project (2030 to 2065) are used to estimate the potential emissions as a result of the Project.

1.5.2.5 A grid-average emissions factor is projected by BEIS for 2040 and the marginal factor is assumed to converge with it by that date, interpolated between 2030 and 2040. Both factors are then interpolated from 2040 to a national goal for carbon intensity of electricity generation in 2050 and assumed to be constant after that point.

1.5.2.6 National Grid publishes 'Future Energy Scenario' (FES) projections (National Grid, 2022) of grid-average carbon intensity under several possible evolutions of the UK energy market. The BEIS grid-average projection sits generally above all the National Grid range, and as stated above, the marginal factor is assumed by BEIS to converge with it (and hence with National Grid's scenarios) over time.

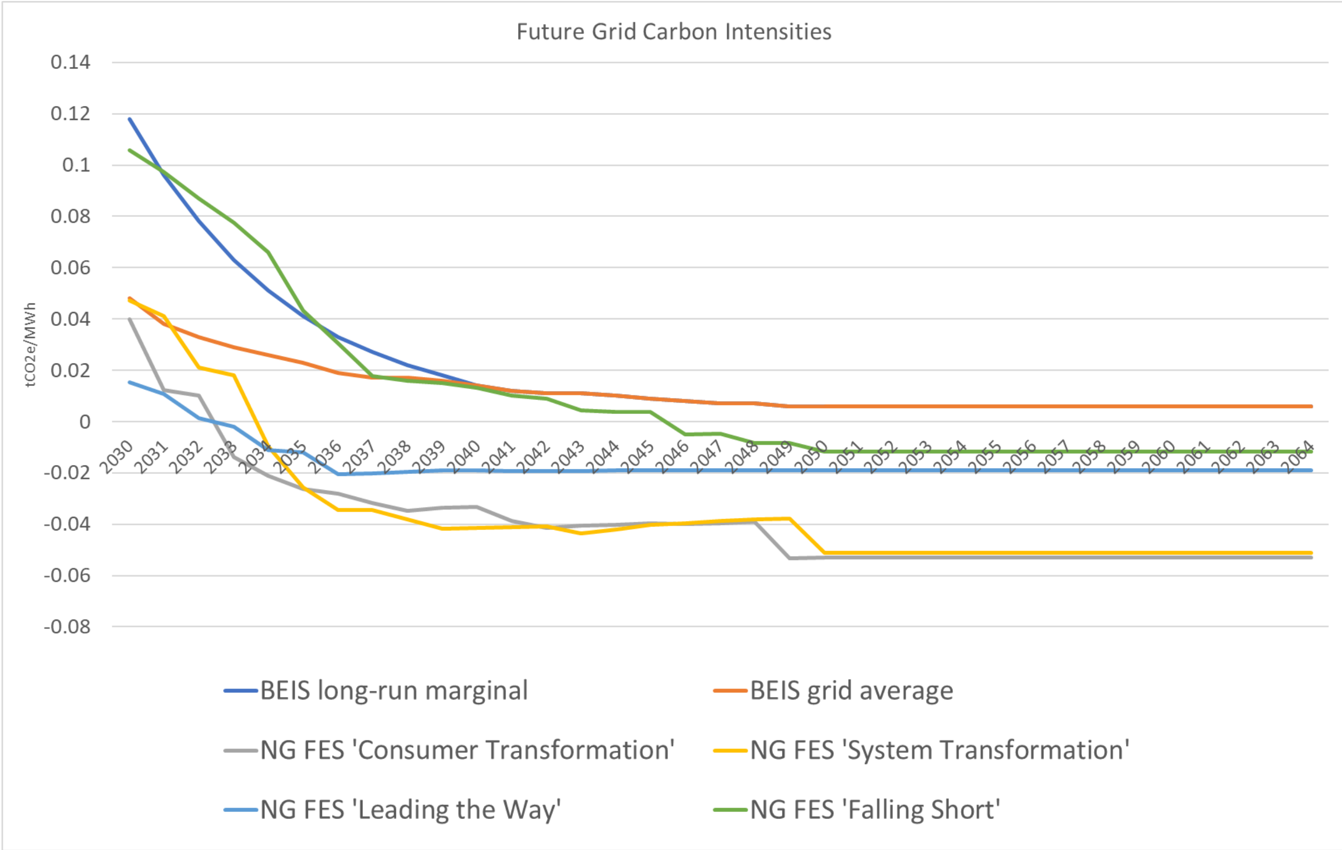

Figure 1.1: BEIS and FES future grid carbon intensities.

1.5.2.7 As can be seen from Figure 1.1, all of the FES grid-average carbon intensity projections achieve net negative values due to the sequestration of biogenic CO_2, via Bioenergy with Carbon Capture and Storage (BECCS). It has been assumed that the Mona Offshore Wind Project would not displace other forms of electricity generation with net negative GHG effects. Figure 1.1 illustrates both the BEIS and National Grid projected carbon intensity factors for displaced electricity generation and Table 1.2 lists the BEIS grid-average and marginal factors for the 35 years of the Mona Offshore Wind Project's operation.

Table 1.2: BEIS grid average and long-run marginal grid carbon intensities.

Year of Operation	Year	BEIS Long-Run Marginal (tCO_2e/MWh)	BEIS Grid Average (tCO_2e/MWh)
1	2030	0.091	0.045
2	2031	0.076	0.038
3	2032	0.063	0.03
4	2033	0.053	0.024
5	2034	0.044	0.019
6	2035	0.037	0.018
7	2036	0.03	0.018
8	2037	0.025	0.017
9	2038	0.021	0.016
10	2039	0.018	0.015
11	2040	0.015	0.015
12	2041	0.014	0.014
13	2042	0.013	0.013
14	2043	0.008	0.008
15	2044	0.008	0.008
16	2045	0.007	0.007
17	2046	0.007	0.007
18	2047	0.005	0.005
19	2048	0.005	0.005
20	2049	0.003	0.003
21	2050	0.002	0.002
22	2051	0.002	0.002
23	2052	0.002	0.002
24	2053	0.002	0.002
25	2054	0.002	0.002
26	2055	0.002	0.002
27	2056	0.002	0.002
28	2057	0.002	0.002
29	2058	0.002	0.002
30	2059	0.002	0.002
31	2060	0.002	0.002
32	2061	0.002	0.002
33	2062	0.002	0.002
34	2063	0.002	0.002
35	2064	0.002	0.002

1.6 Assessment of Construction Effects

1.6.1 Land use change

1.6.1.1 The infrastructure components of the Mona Offshore Wind Project that will alter the onshore and offshore land use comprise:

- onshore substation and associated infrastructure, including permanent access road
- wind turbines and other structures.
- onshore and offshore cable corridors

Onshore

1.6.1.2 Volume 3, chapter 20: Land use and recreation and volume 7, annex 20.1: Agricultural land classification outlines the baseline conditions for the onshore components and any subsequent effects of the Mona Offshore Wind Project on land use.

1.6.1.3 Annex 20.1 highlights areas of woodland located on the western side of the search area, near Gwrych Castle that fall into the Mona Proposed Onshore Development Area and may be of value in relation to carbon storage, however the Mona Offshore Wind Project is to drill under the woodland and not disturb the carbon storage. The annex does not identity any further areas of value due to the nature of the baseline environment as predominantly agricultural farmland. Furthermore, no soil or woodland of high carbon storage value has been identified for each of the onshore substation locations.

Offshore

1.6.1.4 The land use change would be constrained to the red line boundary for the Mona Offshore Wind Project and would not directly impact any carbon stores. The land use would be affected throughout the construction and operations and maintenance phases of the development. However, through the decommissioning process it is anticipated that the existing baseline environment would be restored. As no carbon stores are directly affected by the Mona Offshore Wind Project and the habitat is anticipated to return back to its pre-development habitat after decommissioning the change concerning the carbon storage value of the land use would be minimal.

1.6.2 Embodied carbon

1.6.2.1 The following sections detail the methodology used to calculate the construction stage emissions associated with the Mona Offshore Wind Project.

1.6.2.2 The construction stage emissions cover the LCA stages A1-A5, materials and construction, i.e., emissions associated with the extraction, processing and manufacturing of materials. In addition, emissions associated with the transport of materials and technology to site (within the UK) has been analysed.

1.6.2.3 The materials involved in the offshore components of the Mona Offshore Wind Project are the initial elements to consider within the cradle-to-grave approach towards completing this LCA. Emissions are derived from the raw material production required to manufacture the wind turbine generators, foundations, cables and substations and it is often the stage where the majority of embodied carbon is emitted.

1.6.2.4 There is uncertainty in material quantities at this stage. As such, impacts are calculated utilising the intensity metric as detailed in the Dolan & Heath (2012) LCA study (Table 1.1). The Dolan & Heath (2012) study compiled a total of 126 life cycle assessments from 49 different studies for both onshore and offshore wind. Although this sample size is small, LCA data for offshore turbines is limited, and as such an average of multiple studies is deemed an acceptable proxy. As was detailed in paragraph 1.3.2.5 and Table 1.1 the lifecycle GHG intensity of for LCA Stages A1-A5 of 9.46 $kgCO_2e$/MWh was established.

Table 1.3: Energy flows from Mona Offshore Wind Project.

Parameter	Value	Unit	Source
Input parameter – export capacity rated power	1,500	MW	Project Description
Input parameter – capacity factor	34.5	%	BEIS (2022)
Input parameter – degradation factor	1.6	%	Staffell & Green (2014)
Input parameter – total annual operating hours	8,760	hrs	Mona Offshore Wind Project PDE
Output parameter – life time energy output (35 years)	122,221,092	MWh	N/A

1.6.2.5 It should be noted that the BEIS Allocation Framework for Rounds 3 (BEIS, 2019) and 4 (BEIS 2021) state that all new offshore wind projects shall achieve a load factor of 58.4% and 63.1% respectively. Use of higher load factors within the calculations would result in higher output (MWh) and subsequent avoided emissions. As the MWh output has been used as the base for GHG emission calculations via the use of various intensities (MWh output multiplied by LCA intensity or MWh output multiplied by long run marginal carbon intensity), any increase in emissions or avoided emissions for each phase would be proportionately similar to that of a lower capacity factor. A variation in capacity factor would not only increase the amount of avoided emissions but proportionately the calculated construction, operation and maintenance fuel consumption, and decommissioning GHG emissions. As such, a lower capacity factor (based on average actual offshore wind load factors between 2004 & 2021 as opposed to forward looking projected factors) represents a conservative assumption for this assessment.

1.6.2.6 When applying this intensity to the 122,221,092 MWh operational output across the 35-year design life of the Mona Offshore Wind Project this results in an estimated embodied carbon emission in the order of 1,156,211.53 tCO_2e.

1.6.2.7 As detailed within paragraph 0 there is limited information concerning the substations. The LCA (ABB, 2003) listed a manufacturing GWP of 2,190 $kgCO_2e$ per MW. This was scaled by the Mona Offshore Wind Project output capacity of 1,500 MW to give an estimated embodied emission value of 3,285 tCO_2e. This value includes lifecycle stages A1-A3.

1.6.2.8 At this stage of design, materials estimates have some uncertainty in terms of the amounts and in the grouping into the main categories of material rather than it being possible to specify all products to be used in the final, detailed design. As a means of comparison, a published benchmark (RICS, 2012) has therefore also been used to estimate possible emissions from the substation buildings.

1.6.2.9 The benchmark data is expressed in $kgCO_2e/m^2$ of floorspace as an intensity which is applied against the total floor area for all four substations (105,000 m^2). When using the RICS intensity for other Industrial/utilities/specialist uses with the substation floor area we result in an estimated embodied carbon emission of 57,225 tCO_2e.

1.7 Assessment of Operational Effects

1.7.1 Land use change

1.7.1.1 Considered with construction stage impacts see Section 1.6.1.

1.7.2 Avoided emissions

1.7.2.1 The magnitude of impact of the Mona Offshore Wind Project is determined by the quantity of renewable energy use it enables by avoiding curtailment, the quantity of fossil fuel generation it displaces, and the associated GHG impacts of both. The quantity of renewable energy enabled and fossil fuel generated energy displaced is determined by the total annual energy input and output values for the Mona Offshore Wind Project (see Table 1.4). The associated GHG emissions are determined by the GHG intensity of the enabled and displaced sources of generation.

1.7.2.2 Table 1.4 sets out the annual energy input and output values for the Mona Offshore Wind Project and the parameters by which they are determined.

Table 1.4: Energy flows from Mona Offshore Wind Project.

Parameter	Value	Unit	Source
Input parameter - rated power	1,500	MW	Project Description
Input parameter – capacity factor	34.5	%	BEIS 2022)
Input parameter – degradation factor	1.6	%	Staffell and Green (2014)
Input parameter – total annual operating hours	8,760	hrs	Mona Offshore Wind Project PDE
Output parameter - annual energy output	4,533,300	MWh	Mona Offshore Wind Project PDE

1.7.2.3 The input and output figures for the operational stage of the Mona Offshore Wind Project are then calculated against the assumptions stated within the BEIS long-run marginal, published by the National Grid. This allows for a direct presentation of the cumulative GHG emissions avoided throughout the operational lifetime of the Mona Offshore Wind Project and therefore, how the Project contributes towards reaching net zero targets.

1.7.2.4 The marginal source displaced may in practice vary from moment to moment depending on the operation of the capacity market, i.e. led by commercial considerations and National Grid's needs at any given time. For the purpose of this assessment, longer-term trends (annual averages) have been used as it is not possible to predict shorter-term variations with confidence. It should be noted that as the UK moves towards its 2050 net zero carbon target, the marginal source of electricity generation will likely become a combination of renewables (predominately solar and wind) and storage. Therefore, from circa 2040 onwards, comparing the Mona Offshore Wind Project's GHG impacts with the marginal source of generation is akin to comparing it with itself and has limited value.

1.7.2.5 The BEIS long-run marginal grid carbon intensity factors do not properly consider the embedded construction stage GHG impacts of the sources of generation. It is therefore not a like-for-like comparison to compare the lifetime carbon impacts of the Mona Offshore Wind Project with the BEIS long-run marginal or grid-average source.

1.7.3 Fuel and energy consumption operational and maintenance activities

1.7.3.1 The primary purpose of the operational stage of a wind farm is to avoid the need for fossil fuel generation assets and reduce the national grid carbon intensity. Emissions during the operational phase of the Mona Offshore Wind Project refers to activities contributing to the high-level management of the asset such as remote monitoring, environmental monitoring, electricity sales, etc. Maintenance accounts for by far the largest portion can be divided into preventative maintenance and corrective maintenance.

- Preventative maintenance: proactive repair to, or replacement of, known wear components based on routine inspections or monitoring systems.
- Corrective maintenance includes the reactive repair or replacement of failed or damaged components. It may also be performed batch-wise when serial defects or other problems occur.

1.7.3.2 When using the operational and maintenance intensity (in use LCA Stages B1-B5), as detailed in Table 1.1, of 0.99 kgCO_2e/MWh we can estimate the potential GHG emissions in the order of 120,999 tCO_2e across the 35 year operational life time of the Mona Offshore Wind Project. The combined impact of the fuel and energy related activities in addition to the avoided Grid emissions has been reflected in the below

1.7.3.3 Table 1.5. Additionally, an assumed degradation factor of 1.6% (Staffell and Green, 2014) has been incorporated into the annual output beyond the first year of operation.

1.7.3.4 Table 1.5 displays the annual power output and emissions avoidance of the Mona Offshore Wind Project when comparing the abated fossil fuel generation using the BEIS (2023) long run marginal carbon intensity for the future UK Grid. In addition, the predicted GHG emissions as a result of the operational and maintenance energy use (fuel and purchased electricity) has been presented. When you consider the energy use for operation and maintenance activities in addition to the avoided emissions from grid decarbonisation, we present the total emissions for the operation and maintenance phase.

Table 1.5: Operational GHG impacts.

Year of Operation	Year	Output (MWh)	BEIS long-run marginal (tCO_2e/MWh)	O&M emissions (tCO_2e)	Avoided GHG emissions (tCO_2e)	Combined O&M emissions (tCO_2e)	Cumulative GHG emissions (tCO_2e)
1	2030	4,533,300	0.091	4,488	412,530	-408,042	408,042
2	2031	4,460,767	0.076	4,416	339,018	-334,602	742,644
3	2032	4,389,395	0.063	4,346	276,532	-272,186	1,014,831
4	2033	4,319,165	0.053	4,276	228,916	-224,640	1,239,471
5	2034	4,250,058	0.044	4,208	187,003	-182,795	1,422,266
6	2035	4,182,057	0.037	4,140	154,736	-150,596	1,572,861
7	2036	4,115,144	0.03	4,074	123,454	-119,380	1,692,242
8	2037	4,049,302	0.025	4,009	101,233	-97,224	1,789,466
9	2038	3,984,513	0.021	3,945	83,675	-79,730	1,869,196
10	2039	3,920,761	0.018	3,882	70,574	-66,692	1,935,888
11	2040	3,858,029	0.015	3,819	57,870	-54,051	1,989,939
12	2041	3,796,300	0.014	3,758	53,148	-49,390	2,039,329
13	2042	3,735,559	0.013	3,698	48,562	-44,864	2,084,193
14	2043	3,675,790	0.008	3,639	29,406	-25,767	2,109,960
15	2044	3,616,978	0.008	3,581	28,936	-25,355	2,135,315
16	2045	3,559,106	0.007	3,524	24,914	-21,390	2,156,705
17	2046	3,502,160	0.007	3,467	24,515	-21,048	2,177,753
18	2047	3,446,126	0.005	3,412	17,231	-13,819	2,191,572
19	2048	3,390,988	0.005	3,357	16,955	-13,598	2,205,170
20	2049	3,336,732	0.003	3,303	10,010	-6,707	2,211,877
21	2050	3,283,344	0.002	3,251	6,567	-3,316	2,215,193
22	2051	3,230,811	0.002	3,199	6,462	-3,263	2,218,456
23	2052	3,179,118	0.002	3,147	6,358	-3,211	2,221,667
24	2053	3,128,252	0.002	3,097	6,257	-3,160	2,224,827
25	2054	3,078,200	0.002	3,047	6,156	-3,109	2,227,936
26	2055	3,028,949	0.002	2,999	6,058	-3,059	2,230,995
27	2056	2,980,486	0.002	2,951	5,961	-3,010	2,234,005
28	2057	2,932,798	0.002	2,903	5,866	-2,962	2,236,967

Year of Operation	Year	Output (MWh)	BEIS long-run marginal (tCO_2e/MWh)	O&M emissions (tCO_2e)	Avoided GHG emissions (tCO_2e)	Combined O&M emissions (tCO_2e)	Cumulative GHG emissions (tCO_2e)
29	2058	2,885,873	0.002	2,857	5,772	-2,915	2,239,882
30	2059	2,839,699	0.002	2,811	5,679	-2,868	2,242,750
31	2060	2,794,264	0.002	2,766	5,589	-2,822	2,245,572
32	2061	2,749,556	0.002	2,722	5,499	-2,777	2,248,349
33	2062	2,705,563	0.002	2,679	5,411	-2,733	2,251,082
34	2063	2,662,274	0.002	2,636	5,325	-2,689	2,253,771
35	2064	2,619,677	0.002	2,593	5,239	-2,646	2,256,416

1.7.4 Sensitivity Analysis

1.7.4.1 The long run marginal figures, which have been used in the above Table 1.6, are dynamic and show year-on-year decarbonisation of UK electricity Grid towards the UK's committed net zero 2050 pledge. The long run marginal carbon intensity figures account for variations over time for both generation and consumption activity reflecting the different types of power plants generating electricity across the day and over time, each with different emissions factors. However, the long run marginal figures are projections and cannot be taken with absolute certainty. Furthermore, the long-run marginal includes assumed abatement of fossil fuel generation sources within the UK electricity Grid. As such it is likely that the true value of the avoided emissions displaced as a result of the Mona Offshore Wind Project's contribution to the UK electricity Grid would be higher than that of avoided emissions detailed above.

1.7.4.2 As such, a sensitivity analysis has been carried out using the current UK electricity Grid carbon intensity and current estimated intensity from electricity supplied for 'all non-renewable fuels' as detailed in section 1.5.1.

1.7.4.3 Although the use of the current UK electricity Grid average and BEIS 'non-renewable fuels' carbon intensities would conclude greater avoided emissions and an ultimate reduction in carbon payback period, these are static baselines and do not account for future UK electricity Grid decarbonisation. As such, the long run marginal provides a conservative quantification of avoided emissions for the purpose of this assessment.

Table 1.6: Whole life avoided emissions sensitivity test.

Operating years	Output (MWh)	BEIS long-run marginal avoided emissions (tCO_2e)	Current UK Grid average avoided emissions (tCO_2e)	BEIS 'non-renewable fuels' avoided emissions (tCO_2e)
35	122,221,092	2,377,416	29,287,840	52,799,512

1.7.4.4 Additionally, as detailed in paragraph 0, variations in load factors could have a similar effect on the avoided emissions in addition to other quantifications of emissions. Any change in the load factors would vary the MWh output accordingly. As the MWh output has been used as the base for all phases of calculations using various intensities, any increase in emissions or avoided emissions for each phase would be proportionately similar to that of the above. Construction, operation and maintenance and decommissioning phase emissions would proportionately increase in line with the output (MWh)

1.7.5 Decommissioning

1.7.5.1 The majority of emissions during this phase relate to the use of plant for Mona Offshore Wind Project decommissioning, disassembly, transportation to a waste site, and ultimate disposal and/or recycling of the equipment and other site materials. The components of the wind turbines are considered to be highly recyclable. When disposing of wind turbines, recycling is the preferred solution. This not only prevents the materials from being sent to landfills, but also reduces the need for the extraction of primary materials. Material which cannot be recycled might be used for incineration or energy from waste. Additionally, the carbon emissions associated with use of plant and fuel is expected to have achieved good levels of decarbonisation at the decommissioning phase of the Mona Offshore Wind Project. As such, the above quantified emissions are anticipated to be a maximum design estimate.

1.7.5.2 When using the downstream (LCA Stages C1-C4) intensity from Table 1.1, 0.55 kg CO_2e/MWh with the Mona Offshore Wind Project lifetime energy output of 122,221,092 MWh we can estimate the potential GHG emissions for the decommissioning stage, as detailed in Table 1.7, in the order of 67,222 tCO_2e.

Table 1.7: Decommissioning stage GHG emissions.

LCA Stage	Intensity (kgCO_2e/MWh)	35-year output (MWh)	Mona Offshore Wind Project emissions (tCO_2e)
C1-C4	0.55	122,221,092	67,222

1.8 References

ABB (2003) Environmental Product Declaration: Power transformer TrafoStar 500 MVA. Available: https://library.e.abb.com/public/566748ad75116903c1256d630042f1af/ProductdeclarationStarTrafo500.pdf. Accessed October 2022

Committee on Climate Change (2020) The Sixth Carbon Budget: The UK's path to Net Zero. Available: https://www.theccc.org.uk/wp-content/uploads/2020/12/The-Sixth-Carbon-Budget-The-UKs-path-to-Net-Zero.pdf. Accessed October 2022.

BEIS and Defra (2022) UK Government GHG Conversion Factors for Company Reporting. Available at: https://www.gov.uk/government/collections/government-conversion-factors-for-company-reporting Accessed October 2022.

Department for Business, Energy and Industrial Strategy (2019) Contracts For Difference Scheme For Renewable Electricity Generation Allocation Round 3: Allocation Framework, 2019 Available at:

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/799074/Allocation_Round_3_Allocation_Framework__2019.pdf Accessed January 2023

Department for Business, Energy and Industrial Strategy (2021) Contracts for Difference Scheme for renewable electricity generation Allocation Round 4: Allocation Framework, 2021. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1035899/cfd-allocation-round-4-allocation-framework.pdf Accessed January 2023

Department for Business, Energy and Industrial Strategy (2022) Digest of UK Energy Statistics. Load Factors for renewable electricity generation. Department for Business, Energy and Industrial Strategy. Available at: https://www.gov.uk/government/statistics/renewable-sources-of-energy-chapter-6-digest-of-united-kingdom-energy-statistics-dukes Accessed January 2023.

Department for Business, Energy and Industrial Strategy (2023) Valuation of Energy Use and Greenhouse Gas: Supplementary guidance to the HM Treasury Green Book [online] available at: https://www.gov.uk/government/publications/valuation-of-energy-use-and-greenhouse-gas-emissions-for-appraisal Accessed January 2023.

Dolan, S.L & heath, G.A (2012) Life Cycle Greenhouse Gas Emissions of Utility-Scale Wind Power. Journal of Industrial Ecology. Volume 16 Number S1

HM Government (2021) Net Zero Strategy: Build Back Greener. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1033990/net-zero-strategy-beis.pdf Accessed October 2022.

IPCC (2013) Climate Change 2013: The Physical Science Basis Available: https://www.ipcc.ch/report/ar5/wg1/ Accessed October 2022.

National Grid ESO (2022). Future Energy Scenarios. . Available: https://www.nationalgrideso.com/future-energy/future-energy-scenarios Accessed October 2022.

NREL (2013) Wind LCA Harmonization Available: https://www.nrel.gov/docs/fy13osti/57131.pdf Accessed October 2022.

RICS (2012) RICS Professional Information, UK Methodology to calculate embodied carbon of materials. Available: https://www.igbc.ie/wp-content/uploads/2015/02/RICS-Methodology_embodied_carbon_materials_final-1st-edition.pdf. Accessed October 2022.

Staffell, I. and Green, R. (2014). How does wind farm performance decline with age? Volume 66, Renewable Energy. Available: https://www.sciencedirect.com/science/article/pii/S0960148113005727 Accessed October 2022

WRI and WBSCD (2004) A Corporate Accounting and Reporting Standard Available: https://ghgprotocol.org/sites/default/files/standards/ghg-protocol-revised.pdf Accessed October 2022.