MORGAN OFFSHORE WIND PROJECTS: GENERATION ASSETS

Preliminary Environmental Information Report

Volume 4, annex 17.1: Greenhouse gas assessment technical report


Image of an offshore wind farm

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FINAL

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Acronyms

Acronym	Description
BECCS	Bioenergy with Carbon Capture Storage
DUKES	Digest of UK Energy Statistics
FES	Future Energy Scenario
GHG	Greenhouse Gas
GWP	Global Warming Potential
HGV	Heavy Goods Vehicles
HVAC	High Voltage Alternating Current
IEA	International Energy Agency
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
WBCSD	World Business Council for Sustainable Development
WRI	World Resources Institute

Units

Unit	Description
CO_2e	carbon dioxide equivalent
km	Kilometres
kg	Kilograms
kWh	Kilowatt Hours
MW	Megawatts
MWh	Megawatt Hours
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.
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 TECHNICAL REPORT

1.1 Introduction

1.1.1.1 This Greenhouse gas (GHG) assessment technical report sets out the methodology and calculations of the GHG emissions for the Morgan Offshore Wind Project Generation Assets (referred to hereafter as the Morgan Generation Assets). These calculations inform the assessment of the climate change impacts in volume 2, chapter 17: 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 Morgan Generation Assets. 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 volume 2, chapter 17: 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. The GWPs typically used are 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 scope of this annex relates to the Morgan Generation Assets during the construction, operations and maintenance phase, and decommissioning. This excludes elements relating to the offshore export cable, offshore booster stations and onshore transmission assets which will be assessed separately as part of the Morgan and Morecambe Offshore Wind Farms Transmission Assets Development Consent Order (DCO). Key emissions sources included within this assessment are:

- Offshore sea bed change
- Embodied carbon emissions in materials (wind turbine generators, offshore substations, inter-array and inter-connector cabling)
- Transport emissions
- Decommissioning of Generation Assets.

1.2.1.3 Avoided emissions associated with the abatement of required fossil fuel generators and their associated emissions related with the UK electricity grid. Emissions presented as part of the generation asset to be realised at point of grid connection as part of the Morgan and Morecambe Offshore Wind Farms Transmission Assets DCO application.

1.3 Methodology

1.3.1 Overview

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 Morgan Generation Assets, have been informed via the following sources:

- 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 Morgan Generation Assets. These emissions shall not be separated out by defined scopes (Scopes1, 2 or 3) in the assessment.

1.3.1.4 Due to the nature of the Morgan Generation Assets, i.e. exporting generated electricity to the grid, its gross GHG emissions total is dominated by avoided scope 2 emissions. The avoided scope 2 emissions are those that would have occurred as a result of the predicted UK Grid Carbon Intensity without the Morgan Generation Assets.

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

- Life Cycle Assessment Harmonization Project (NREL, 2013)
- Life Cycle Greenhouse Gas Emissions of Utility-Scale Wind Power (Dolan & 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 Morgan Generation Assets, (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 Morgan Generation Assets is required in order to quantify its net contribution to climate change and as such the magnitude of change owing to the Morgan Generation Assets.

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 (Morgan Generation Assets 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)
- operations and maintenance (B1-B5)
- decommissioning (C1-C4).

1.3.2.2 As the Morgan Generation Assets 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 (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 Morgan Generation Assets was a study by National Renewable Energy Laboratory (NREL, 2013) Life Cycle Assessment Harmonization Project and Dolan & Heath (2012).

1.3.2.4 The NREL 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 smaller sample size of 49 different studies.

1.3.2.5 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.

1.3.2.6 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 operations and maintenance
- downstream (decommissioning stage).

1.3.2.7 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.

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 consider the impact of the Morgan Generation Assets 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 would also consider the GHG emissions that would not be generated (i.e. avoided) during the operation of the Morgan Generation Assets during the future baseline (see section 1.7.3).

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 UKs 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 Morgan Generation Assets.

1.4.1.2 Principal sources relied upon for the quantification of GHG emissions for the Morgan Generation Assets 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 Morgan Generation Assets. Government projections consistent with national carbon budget commitments have been used in the assessment.

1.4.1.4 The specific wind turbine technology and design of associated infrastructure (including substations etc.) that would be used by the Morgan Generation Assets have not yet been specified. Thus, there is a degree of uncertainty regarding the all project-stages 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 With regard to GHG emissions, the current baseline is the marine and sedimentary uses for the Morgan Generation Assets area, including inter-array and interconnector cables, which is to be temporarily displaced. Carbon sequestration rates in marine habitats are usually lower than those of terrestrial habitats. The baseline consists of various subtidal habitats of stony reef, subtidal course, mixed sediments and diverse benthic communities

1.5.1.2 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 239.63kg 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 Morgan Generation Assets are expected to remain similar to the current baseline identified above (section 1.5.1).

1.5.2.2 The future baseline for electricity generation that would be displaced by the Morgan Generation Assets 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 Morgan Generation Assets, 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' projections over the predicted operating lifetime of the Morgan Generation Assets (2030 to 2065) are used to estimate the potential emissions as a result of the Morgan Generation Assets.

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.

1.5.2.7 As can be seen in 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 Morgan Generation Assets 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 Morgan Generation Assets operation.

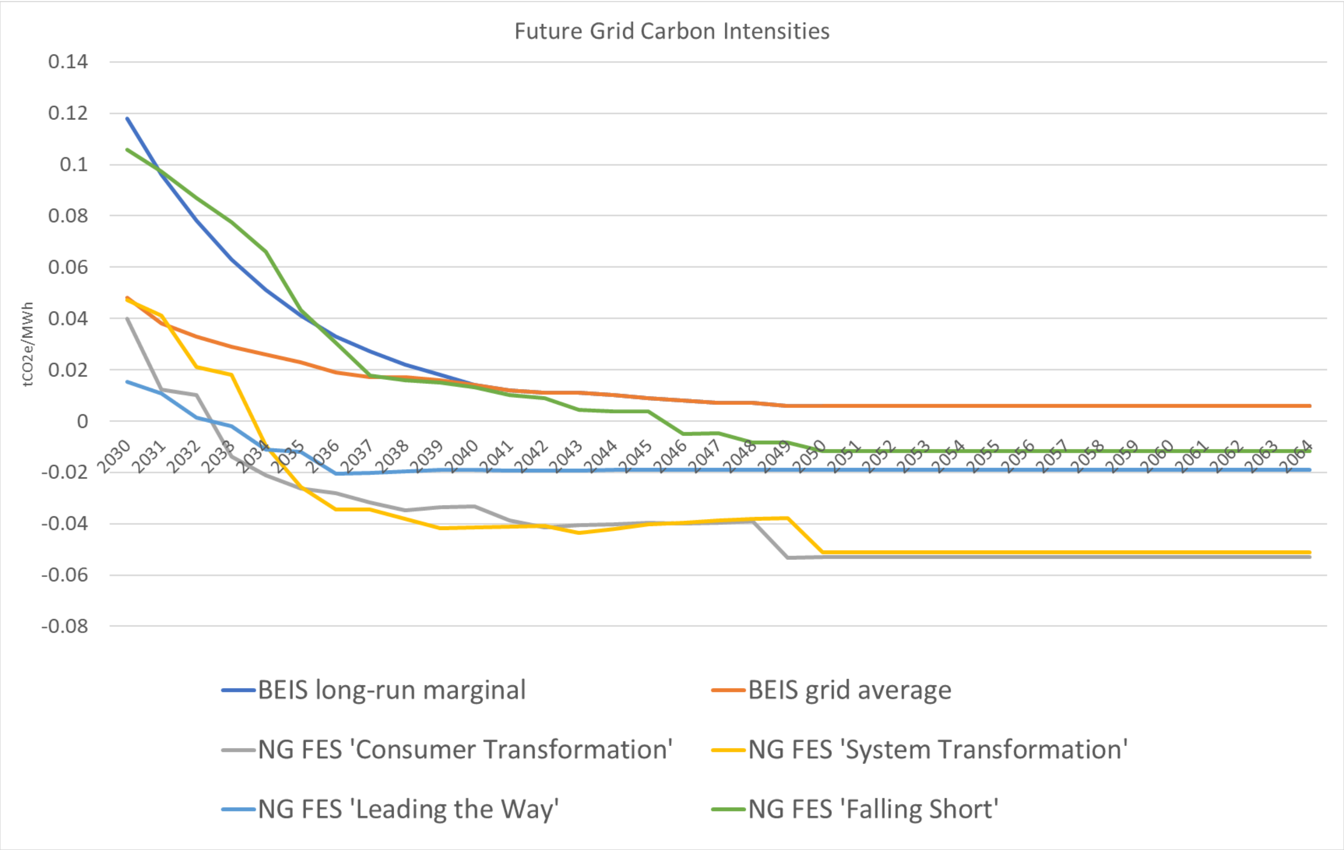

Figure 1.1: BEIS and FES future grid carbon intensities.

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

Year of Operation	Year	BEIS Long-Run Marginal (tCO_2e/MWh)	BEIS Grid Average (tCO_2e/MWh)
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 Morgan Generation Assets that will alter the offshore land use comprise:

- Wind turbines and associated components (monopiles etc.)
- Offshore substation platforms
- Inter-array cables
- Interconnector cables.

1.6.1.2 The land use change would be constrained to the red line boundary for the Morgan Generation Assets and would not directly impact any carbon stores. The land use would be affected throughout the construction and operations and maintenance phases of the Morgan Generation Assets. 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 Morgan Generation Assets and the habitat is anticipated to return back to its pre-development habitat after decommissioning the magnitude of impact is therefore, considered to be negligible.

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 Morgan Generation Assets.

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 Morgan Generation Assets 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 1.3.2.6 and Table 1.1 the lifecycle GHG intensity of for LCA Stages A1-A5 of 9.46 gCO_2e/kWh was established.

Table 1.3: Energy flows from Morgan generation Assets

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 & Green (2014)
Input parameter – total annual operating hours	8,760	hrs	Morgan Generation Assets 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 Morgan Generation Assets this results in an estimated embodied carbon emission in the order of 1,156,212 t CO_2e.

1.6.2.7 As is detailed in paragraph 1.3.2.8 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 Morgan Generation Assets 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 kg CO_2e/m^2 of floorspace as an intensity which is applied against the total floor area for all four substations (19,200 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 10,464 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 Morgan Generation Assets is determined by the quantity of renewable energy use it enables by avoiding curtailment, the quantity of peaking plant generation it displaces, and the associated GHG impacts of both. The quantity of renewable energy enabled and peaking plant energy displaced is determined by the total annual energy input and output values for the Morgan Generation Assets (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 Morgan Generation Assets and the parameters by which they are determined.

Table 1.4: Energy flows from Morgan Generation Assets.

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	Whole year of operation
Output parameter - annual energy output	4,533,300	MWh	N/A

1.7.2.3 The input and output figures for the operations and maintenance stage of the Morgan Generation Assets are then calculated against the assumptions stated within the FES, published by the National Grid. This allows for a direct presentation of the cumulative GHG emissions avoided throughout the operational lifetime of the Morgan Generation Assets and therefore, how the Morgan Generation Assets 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 Morgan Generation Assets' 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 Morgan Generation Assets with the BEIS long-run marginal or grid-average source.

1.7.3 Fuel and energy consumption operations 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 operations phase of the Morgan Generation Assets 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 operations and maintenance intensity (in use LCA Stages B1-B5), as detailed in Table 1.1, of 0.99g CO_2e/kWh we can estimate the potential GHG emissions in the order of 120,999 tCO_2e across the 35 year operational life time of the Morgan Generation Assets.

1.7.3.3 The combined impact of the fuel and energy related activities in addition to the avoided Grid emissions has been reflected in the below 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 Morgan Generation Assets when comparing the abated fossil fuel generation using the BEIS (2023) long run marginal carbon intensity for the future UK electricity 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 (tCO2e/MWh)	O and 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	4,487.97	-412,530	-408,042	-408,042
2	2031	4,460,767	0.076	4,416.16	-339,018	-334,602	-742,644
3	2032	4,389,395	0.063	4,345.50	-276,532	-272,186	-1,014,831
4	2033	4,319,165	0.053	4,275.97	-228,916	-224,640	-1,239,471
5	2034	4,250,058	0.044	4,207.56	-187,003	-182,795	-1,422,266
6	2035	4,182,057	0.037	4,140.24	-154,736	-150,596	-1,572,861
7	2036	4,115,144	0.03	4,073.99	-123,454	-119,380	-1,692,242
8	2037	4,049,302	0.025	4,008.81	-101,233	-97,224	-1,789,466
9	2038	3,984,513	0.021	3,944.67	-83,675	-79,730	-1,869,196
10	2039	3,920,761	0.018	3,881.55	-70,574	-66,692	-1,935,888
11	2040	3,858,029	0.015	3,819.45	-57,870	-54,051	-1,989,939
12	2041	3,796,300	0.014	3,758.34	-53,148	-49,390	-2,039,329
13	2042	3,735,559	0.013	3,698.20	-48,562	-44,864	-2,084,193
14	2043	3,675,790	0.008	3,639.03	-29,406	-25,767	-2,109,960
15	2044	3,616,978	0.008	3,580.81	-28,936	-25,355	-2,135,315
16	2045	3,559,106	0.007	3,523.52	-24,914	-21,390	-2,156,705
17	2046	3,502,160	0.007	3,467.14	-24,515	-21,048	-2,177,753
18	2047	3,446,126	0.005	3,411.66	-17,231	-13,819	-2,191,572
19	2048	3,390,988	0.005	3,357.08	-16,955	-13,598	-2,205,170
20	2049	3,336,732	0.003	3,303.36	-10,010	-6,707	-2,211,877
21	2050	3,283,344	0.002	3,250.51	-6,567	-3,316	-2,215,193
22	2051	3,230,811	0.002	3,198.50	-6,462	-3,263	-2,218,456
23	2052	3,179,118	0.002	3,147.33	-6,358	-3,211	-2,221,667
24	2053	3,128,252	0.002	3,096.97	-6,257	-3,160	-2,224,827
25	2054	3,078,200	0.002	3,047.42	-6,156	-3,109	-2,227,936
26	2055	3,028,949	0.002	2,998.66	-6,058	-3,059	-2,230,995
27	2056	2,980,486	0.002	2,950.68	-5,961	-3,010	-2,234,005
28	2057	2,932,798	0.002	2,903.47	-5,866	-2,962	-2,236,967
29	2058	2,885,873	0.002	2,857.01	-5,772	-2,915	-2,239,882
30	2059	2,839,699	0.002	2,811.30	-5,679	-2,868	-2,242,750
31	2060	2,794,264	0.002	2,766.32	-5,589	-2,822	-2,245,572
32	2061	2,749,556	0.002	2,722.06	-5,499	-2,777	-2,248,349
33	2062	2,705,563	0.002	2,678.51	-5,411	-2,733	-2,251,082
34	2063	2,662,274	0.002	2,635.65	-5,325	-2,689	-2,253,771
35	2064	2,619,677	0.002	2,593.48	-5,239	-2,646	-2,256,416.73

1.7.4 Sensitivity Analysis

1.7.4.1 The long run marginal figures, which have been used in the above Table 1.5 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 Morgan Generation Assets' 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 1.6.2.5, 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 Morgan Generation Assets 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 Morgan Generation Assets. 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 g CO_2e/kWh with the Morgan Generation Assets 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/MW)	35 year output (MWh)	Morgan Generation Assets Emissions (tCO_2e)
C1-C4	0.55	122,221,092	67,222

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