Dublin Array
Generation for generations

EIAR Volume 4: Offshore Infrastructure Technical Appendices
Appendix 4.3.18-1: Greenhouse Gas Assessment Report

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Dublin Array Offshore Wind Farm

Environmental Impact Assessment Report

Greenhouse Gas Assessment Report

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Making Sustainability Happen

Revision Record

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Basis of Report

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Glossary

Term	Definition
Carbon intensity	The amount of carbon (in CO_2 emissions) released per unit of electricity consumed, typically measured in grams of CO_2 per kilowatt-hour (gCO_2/kWh).
Combined Cycle Gas Turbine (CCGT)	A type of power plant that uses both gas and steam turbines to generate electricity, improving efficiency by using the waste heat from the gas turbine to produce steam for the steam turbine.
Dublin Array	Dublin Array Offshore Wind Farm. Where the context so provides within the EIAR, references to Dublin Array refer to all geographical areas of the proposed development, i.e. both offshore, onshore and including the proposed O&M Base.
Embodied carbon	The total greenhouse gas emissions (CO_2eq) associated with the production, transportation, and installation of a product or material, including raw material extraction and manufacturing processes.
GHG emissions	The release of greenhouse gases into the atmosphere, which contribute to global warming and climate change. Common greenhouse gases include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).
Landfall	The location where the Offshore Export Cable Corridor comes ashore adjacent to the Shanganagh Waste Water Treatment Works (WWTW).
Lifecycle Assessment (LCA)	A technique to assess environmental impacts associated with all the stages of a product's life from cradle to grave (i.e. from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling).
Offshore Infrastructure	Wind turbine generators, offshore substation platform, inter array cables, and offshore export cables.
Offshore Substation Platform (OSP)	Offshore substation, which is necessary to connect the WTGs with the Offshore Export Cable.
Offshore Export Cable Corridor (ECC)	The area within which the offshore export cables will be installed.
Operations and Maintenance Base (O&M Base)	The maintenance building for the project, which houses a control room with staff who monitor its electricity output, wind speed, turbine performance, and the movements of vessels around the project site.
Proposed Development	The offshore Dublin Array Offshore Wind farm project elements to which this Offshore EIA Report relates.
Renewable energy	Energy from sources that are naturally replenishing and virtually inexhaustible, such as wind, solar, hydro, and geothermal energy.
Transition Joint Bay (TJB)	The proposed infrastructure at the Landfall location where the offshore and onshore cables connect.
Wind Turbine Generator (WTG)	The wind turbines that generate electricity consisting of tubular towers and blades attached to a nacelle housing mechanical and electrical generating equipment.

Acronyms and Abbreviations

Term	Definition
AR5	Fifth Assessment report
AR6	Sixth Assessment Report
BEIS	Department for Business, Energy and Industrial Strategy
CCGT	Combined Cycle Gas Turbine
CO_2eq	Carbon dioxide equivalents
ECC	Export Cable Corridor
EIA	Environmental Impact Assessment
GHG	Greenhouse Gas
gCO_2/kWh	Grams of CO_2 per kilowatt hour
GW	Gigawatt
Mt	Million tonnes
MW	Megawatt
MWh	Megawatt hour
GWh/yr	Gigawatt hour per year
GWP	Global Warming Potential
GWP100	Global Warming Potential over a 100-year timeframe
IEMA	Institute of Environmental Management and Assessment
IPCC	Intergovernmental Panel on Climate Change
IPCC AR5	Intergovernmental Panel on Climate Change Fifth Assessment Report
IPCC AR6	Intergovernmental Panel on Climate Change Sixth Assessment Report
ISO	International Standards Organisation
LCA	Life Cycle Assessment
MHWS	Mean High Water Springs
MLWS	Mean Low Water Springs
OSP	Offshore Substation Platform
O&M	Operation and maintenance
OSS	Onshore Substation
OWF	Offshore Wind Farm
RICS	Royal Institution of Chartered Surveyors
t	Tonne
tkm	Tonne-kilometre
ktkm	Thousand Tonne-kilometres
WTG	Wind Turbine Generator

1.0 INTRODUCTION

Dublin Array Offshore Wind Farm (hereafter referred to as Dublin Array) is a proposed offshore wind farm located on the Kish and Bray Banks, approximately 10 km off the east coast of Ireland. The Kish and Bray Banks are located off the coast of counties Dublin and Wicklow.

The development of offshore wind farms plays a significant role in advancing renewable energy generation and supporting global efforts to mitigate climate change. A comprehensive Greenhouse Gas (GHG) assessment is essential to understand and quantify the carbon footprint associated with the entire lifecycle of an offshore wind farm project, encompassing construction, operation, maintenance, and decommissioning phases.

GHG emissions embedded in these phases arise from a variety of activities, such as the manufacturing and transportation of construction materials, on-site assembly and installation, routine and emergency maintenance operations, and the eventual decommissioning and disposal of infrastructure.

The need for a GHG assessment is driven by both regulatory requirements and the overarching goal of ensuring that renewable energy projects align with national and international climate targets. The Guidelines for Information to be Included in an Environmental Impact Assessment Report (EIAR) (EPA, 2022) states that assessing GHG emissions and their impact on climate is a necessary component of evaluating the environmental implications of a project.

This assessment forms an important part of the EIAR, and should be read in conjunction with Volume 2, Chapter 18: Climate Change.

1.1 FRAMEWORK FOR GHG ASSESSMENT

The climate change impacts of a product, process, service or installation can be determined using a technique known as Life Cycle Assessment (LCA). The International Standards Organisation (ISO), in its series ISO 14040-44, defines LCA to be the “compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle”, and outlines the four-step method adopted for this analysis. The sections that follow cover each of these steps in turn, explaining:

- Setting the system boundary to define the scope of work;
- Collecting the necessary data for the modelling;
- Bringing together the flow data and characterisation factors; and
- Interpreting and reporting the results.

The relative contributions that different GHGs make towards climate change are denoted by the Global Warming Potential (GWP) of each gas, relative to the chosen reference gas, carbon dioxide (CO_2). As the gases dissipate at different rates in the atmosphere, the GWP of gases varies according to the timeframe of the analysis. Whilst datasets exist for GWP over 20-year and 500-year timeframes, the usual basis for international analysis and reporting is 100-years (GWP100).

Within this timeframe, the United Nations Intergovernmental Panel on Climate Change (IPCC) has published a series of Assessment Reports to provide the latest scientific opinion on the GWP factors that should be used. The most recently issued GWP results are from the Sixth Assessment Report (AR6); however, the latest UK government carbon reporting factors for 2023 are currently based on Fifth Assessment Report (AR5; UN IPCC, 2013), and so the GWP factors used in this report are based on that report and are presented in Table 1-1. Table 1-1 lists all the gases that contribute to the total reported, and no significant emissions are thought to be excluded from the calculations.

Table 1-1 GWP100 factors (from AR5) used in this analysis

Greenhouse gas	GWP100 factor (in kg CO_2eq per kg)
Carbon dioxide (CO_2)	1
Methane (CH_4)	28
Nitrous Oxide (N_2O)	265
Sulphur Hexafluoride (SF_6)	23,500

2.0 SETTING THE GOAL AND SCOPE FOR ANALYSIS

The scope and definitions of the assessment include determining the GHG emissions across the entire lifecycle of the project and comparing them to emissions from equivalent electricity generation.

A summary of the proposed development follows:

- Offshore wind farm infrastructure which will comprise between 39 and 50 number of wind turbine generators (WTGs) with a maximum blade tip height (when a rotor blade is in a vertical orientation) of between 267.6 m to 309.6 m Lowest Astronomical Tide (LAT) and a minimum blade tip height of 31.6 m LAT;
- Associated offshore infrastructure including subsea foundations, subsea inter array electricity cables, scour protection, an offshore substation platform and offshore electricity export cables;
- Transition Joint Bay (TJB) which will be located at the proposed landfall location where the offshore export cables will come ashore. The proposed Landfall/TJB is located at Shanganagh Cliffs, Shanganagh;
- The Onshore Electrical System (OES) is the onshore infrastructure that is necessary to facilitate the operation of the wind farm through the transmission of the electricity generated by the wind farm to the national electricity transmission system. The OES comprises of underground electricity transmission cables, associated fibre-optic communications cables, and the onshore substation. The onshore substation is proposed to be located adjacent to the former Ballyogan landfill site on Ballyogan Road, Carrickmines. Underground electricity cable circuits will connect the onshore substation to the existing Carrickmines 220 kV transmission station operated by ESB Networks and EirGrid;
- The Operations and Maintenance (O&M) Base will be located at Dún Laoghaire Harbour which will provide offices and warehouse space, berthing facilities for crew transfer vessels associated with the construction, operation and maintenance of the Dublin Array.

As detailed in Volume 2, Chapter 6: Project Description, it is not possible to determine the final design solution for Dublin Array at the current time given the anticipated future changes in the design and availability of wind farm components, with the potential to deliver greater efficiency and reduce environmental impacts. As a result, the Applicant is seeking development permission for three project design options in line with the design flexibility opinion from An Bord Pleanála (ABP). The details of each project design option are set out in Volume 2, Chapter 6: Project Description.

This GHG assessment has considered 60 different scenario combinations involving various turbine sizes, numbers, foundation types for WTG, and offshore platforms (OSP), as detailed in Table 2-1.

Table 2-1 Scope of GHG Assessment

Topic	Decision
Study goal:	To determine the GHG emissions from the lifetime operations of the Project, and to compare them with emissions that would be avoided by displacing fossil fuel generation.
Scenarios:	Sixty scenario combinations were examined, considering deployment of three combination options of turbine sizes and numbers, five WTG foundation types, and four Offshore Platform (OSP) foundation types.
Time:	Based in the near present and so using current estimations of material production impacts.
Geography:	Located in the Republic of Ireland, but also cognisant of materials sourced from around the world.
Functional unit:	Calculations to initially determine the total emissions across the lifetime of the installation, then factor in the total electricity produced to scale emissions to a carbon intensity of generation, in grams of CO_2/kilowatt hours (g CO_2/kWh).
Impact criteria:	Only global warming potential (climate change) over a 100-year timeframe was considered in this study.
Data sources:	Detailed in Section 3.0 – a combination of primary data from the developers and literature data.
Life-cycle stages:	All life cycle stages, from cradle to grave.

3.0 DATA COLLECTION

A comprehensive LCA study requires gathering detailed data across all stages of the offshore wind farm's lifecycle, spanning an assumed 35 years of operational period. This involves collecting data from the across six stages of the life cycle:

- Raw Materials;
- Manufacturing;
- Installation;
- Operation;
- Freight; and
- End of Life.

This section provides more detail on the data collected for each of the six stages, in line with information provided in Volume 2, Chapter 6: Project Description.

3.1 RAW MATERIALS

The term 'Raw Materials' refers to the environmental impacts embedded in the construction materials of the Dublin Array, excluding their fabrication or installation, which are addressed in later stages. The Applicant provided detailed information on the materials anticipated for use, such as those required for the WTGs. This data was supplemented with figures provided through a custom template, outlining the quantities expected for construction. The materials for the onshore substation are deemed sufficient to represent a fully enclosed substation, reflecting a reasonable greatest impact scenario for embodied carbon. The main components and their weights are presented in Table 3-1. For the purposes of undertaking a robust, conservative analysis, it was assumed that these materials did not contain any recycled content and were sourced entirely from newly extracted materials.

The three array options detailed in Volume 2, Chapter 6: Project Description include a 39 WTG layout, 45 WTG layout and a 50 WTG layout. In addition to these array layout options, five scenarios for the WTG foundation design, and four scenarios for the OSP foundation design have been included in the GHG assessment.

For the main three options, 'Option A' consists of 50 15-megawatt (MW) WTGs, 'Option B' consists of 45 18 MW WTGs, and 'Option C' consists of 39 21.5 MW WTGs. The five WTG foundation options have been named 1, 2, 3, 4 and 5, and consist of the following:

- Option 1 (monopile, TP, steel, grout and cement);
- Option 2 (jacket & pin-pile and steel, 3 leg structure);
- Option 3 (jacket & pin-pile and steel, 4 leg structure);
- Option 4 (jacket & pin-pile and grout, 4 leg structure); and
- Option 5 (jacket suction bucket foundation, steel and grout, 4 leg structure).

The four OSP foundation options have been named options 1, 2, 3 and 4, and consist of the following:

- Option 1 (jacket & pin-pile steel, 4 leg structure);
- Option 2 (monopile, TP, J-Tube cage and steel);
- Option 3 (monopile & grout); and

- Option 4 (jacket & grout).

Table 3-1 Main materials in the Dublin Array components, and their amounts (indicative values)

Description	Detail	Option A	Option B	Option C	Units
WTG Tower	Steel	72,500	65,200	89,700	(t)
	Aluminium	1,000	900	1,170	t
WTG Blades	Carbon fibre	9,750	8,780	10,700	t
WTG Nacelle	Copper	9,500	8,550	0	t
	Oil & Grease	213	192	166	t
	Steel	41,300	37,100	32,200	t
	Polymer	1,250	1,130	975	t
	Neodymium	1,100	990	858	t
WTG foundation option A (monopile, TP, steel, grout and cement)	Steel	202,000	192,000	181,000	t
	Cement	175,000	182,000	162,000	t
WTG foundation option B (jacket & pin-pile and steel, 3 leg structure)	Steel	250,000	246,000	232,000	t
	Cement		0		t
WTG foundation option C (jacket & pin-pile and steel, 4 leg structure)	Steel	271,000	269,000	257,000	t
	Cement		0		t
WTG foundation option D (jacket & pin-pile and grout, 4 leg structure)	Steel		0		t
	Cement	369,000	385,000	382,000	t
WTG foundation option E (jacket suction bucket foundation, steel and grout, 4 leg structure)	Steel	179,000	177,000	161,000	t
	Cement	63,600	73,500	0	t
OSP foundation option A (jacket & pin-pile steel, 4 leg structure)	Steel		4,000		t
	Cement		0		t
OSP Foundation option B (monopile, TP, J-Tube cage and steel)	Steel		4,200		t
	Cement		0		t
OSP foundation option C (monopile & grout)	Steel		0		t
	Cement		2,380		t
OSP foundation option D (jacket & grout)	Steel		0		t
	Cement		24,900		t
Offshore export cables	Aluminium		1,350		t

Description	Detail	Option A	Option B	Option C	Units
	Copper		3,390		t
	Steel		11,300		t
	Lead		12,400		t
	Plastic		30,800		t
300 AL inter array cable	Aluminium		68		t
	Copper		40		t
	Steel		365		t
	Polymer		169		t
630 AL inter array cable	Aluminium		212		t
	Copper		58		t
	Steel		638		t
	Polymer		346		t
800 CU inter array cable	Copper		969		t
	Steel		685		t
	Polymer		412		t
Offshore substation	Steel		1,513		t
OSP topside	Steel		2,890		t
Fluids & gases	Diesel		3		t
	SF6		2		t
	Battery		5		t
Onshore cable	Aluminium		72		t
	Copper		72		t
	Steel		504		t
	Plastic		72		t
TJB	Concrete		250		m^3
	Steel		25		t
Onshore substation	Concrete		8,000		m^3
	Fill		160,000		t
	Fencing		3		t
	Reinforcement		600		t
	Chippings		6,050		t
	Drainage		2		t
	Structural Steel		1,200		t
	Cladding		5,800		m^2
	Asphalt		7,200		m^3

Description	Detail	Option A	Option B	Option C	Units
	Steel		500		t
	Rebar		700		t
	Loose aggregate		9,240		t
O&M Base	Construction		836		m²

3.2 MANUFACTURING

The values in the previous section primarily account for the production of raw material, such as a tonne of steel. Additional emissions arise during the manufacturing of wind farm components from these materials. Based on our experience, collecting precise manufacturing data for all components is not feasible, and many components would contribute negligibly to the overall impact. However, it was deemed appropriate to estimate manufacturing emissions for certain key materials. The weights cited were derived from the data in Table 3-1 and are presented for the three layout options.

Given the total of sixty potential scenarios, only the best-case (lowest emission) and worst-case (highest emission) combinations of options are presented from each scenario. As shown, the primary variable influencing emissions is the amount of steel used in manufacturing. The combinations assessed are detailed in Table 3-2.

Some of the foundation option combinations have identical manufacturing impacts, as the changes between them do not affect the manufacturing burden but affect other areas such as freight. Because of this, the “least impact option” for manufacturing contains both OSP option 3 and 4, as either option still results in the lowest emissions.

The manufacturing emissions for the key materials are detailed in Table 3-3.

Table 3-2 Details of least impact and greatest impact foundation option combinations for each scenario

Scenario	Option A	Option B	Option C
Best-case	WTG option 4 OSP options 3 & 4	WTG option 4 OSP options 3 & 4	WTG option 4 OSP options 3 & 4
Worst-case	WTG option 3 OSP option 2	WTG option 3 OSP option 2	WTG option 3 OSP option 2

Table 3-3 Materials weights separately assigned manufacturing burdens

Description	Detail	Option A	Option B	Option C	Units
Metal working	Aluminium	2,700	2,600	2,870	t
	Copper	14,000	13,100	4,530	t
	Lead		12,400		t
	Steel (best case) Steel (worst case)	135,000 410,000	123,000 397,000	143,000 404,000	t t
Plastic pipe production	Polyethylene		2		t

3.3 INSTALLATION

The installation stage encompasses the works associated with constructing Dublin Array. Table 3-4 presents the typical expected consumption and usage data for various aspects of installation process. The choice of WTG foundation and OSP foundation options does not affect these numbers, therefore addressing different option combinations is not necessary for this stage.

Table 3-4 Installation stages separately assigned burdens

Description	Detail	Option A	Option B	Option C	Units
Construction	Diesel	64,500	58,100	51,600	t
Boulder clearance	Diesel		200		t
Scour protection installation	Diesel	2,000	2,630	3,300	t
Construction transport	Vessel movements		111,000,000		tkm

3.4 OPERATION AND MAINTENANCE

During operational phase of Dublin Array, vessel movements will be required to maintain the installation in optimal condition. Table 3-5 provides a summary of the anticipated vessel movements throughout the operational phase of Dublin Array. The choice of WTG foundation and OSP foundation options does not influence these numbers, so identifying different option combinations is not necessary.

Table 3-5 Vessel activities during operation and maintenance (across lifetime)

Description	Detail	Option A	Option B	Option C	units
O&M transport	Vessel movements	13,940	13,920	13,890	ktkm

It is anticipated that maintenance work will include regular replacement of various materials. The predicted material requirement was based on the worst-case value calculated using an RWE estimation tool, with a 20% contingency added. The anticipated materials required are summarised in Table 3-6.

Table 3-6 Anticipated materials required for maintenance/replacement (across lifetime)

Description	Detail	Option A	Option B	Option C	units
WTG fluids & gases	Oil & grease	20,100	18,700	16,200	t
	Nitrogen	31,200	28,100	24,300	t
	SF6	30	27	23	t
	Coolant	31,400	28,300	24,500	t
	Battery	50	45	39	t

It is expected that Dublin Array will consume a relatively low level of grid electricity to maintain efficient operation. Although there is some uncertainty regarding the exact level of consumption, the estimate used in these calculations, based on data from other offshore wind farms in the British Isles, assumes that approximately 0.1% of the electricity generated by Dublin Array will be needed.

3.5 FREIGHT

In addition to the vessel movements already discussed, the calculations also account for the freight need to transport construction and maintenance materials to the local area and, at end of life, to remove materials for recycling or disposal. As noted in Table 2-1, these distances are currently based on indicative estimates and locations. The estimated total additional freight movements required, measured in thousands of tonne-kilometres (ktkm) by road and by sea, are presented in Table 3-8 and Table 3-9.

Similar to the Manufacturing stage, only the best-case (lowest emission) combination of options and worst-case (highest emission) combination of options are presented from each scenario. These combinations are detailed in Table 3-7.

Table 3-7 Details of least impact and greatest impact foundation option combinations for each scenario

Scenario	Option A	Option B	Option C
Best-case	WTG option 5 OSP option 3	WTG option 2 OSP option 3	WTG option 5 OSP option 3
Worst-case	WTG option 1 OSP option 4	WTG option 4 OSP option 4	WTG option 4 OSP option 4

Table 3-8 Additional anticipated freight requirements for best case scenario

	Road ktkm			Ship ktkm		
	Option A (best-case)	Option B (best-case)	Option C (best-case)	Option A (best-case)	Option B (best-case)	Option C (best-case)
Raw materials	63,900	63,200	62,700	4,900,000	4,910,000	4,980,000
End of life	29,800	28,800	28,800		0	

Table 3-9 Additional anticipated freight requirements for worst-case scenario

	Road ktkm			Ship ktkm		
	Option A (worst-case)	Option B (worst-case)	Option C (worst-case)	Option A (worst-case)	Option B (worst-case)	Option C (worst-case)
Raw materials	90,800	88,400	85,600	7,190,000	7,040,000	6,920,000
End of life	31,700	30,000	30,400		0	

3.6 DECOMMISSIONING (END OF LIFE)

It is challenging to predict how Dublin Array's materials will be managed at the decommissioning stage, as this stage will occur approximately 35 years from now, when available technology and practices may be significantly different. However, the use of the "cut-off" approach for accounting for recycled content and recycling reduces the criticality of this uncertainty. Under this framework, Dublin Array could receive credit for any recycled materials utilised during its lifetime, as these materials typically have lower embedded carbon compared to raw, unprocessed materials. For the purposes of a robust assessment, it has been assumed that all materials are unprocessed, as noted in the Raw Materials section.

At the end of their life, materials must be managed until they are either recycled or disposed of. For wind turbine infrastructure, this includes transportation to recycling or disposal facilities, but once the materials reach the point where they are ready to be recycled, they exit the analysis boundary of this report and are not considered further. Emissions associated with landfill disposal should be included, but it is anticipated that inert materials will produce minimal, if any, emissions whilst in landfill due to their low or non-existant organic composition. Consequently, the primary burden at this stage is limited to the freight impacts mentioned above.

4.0 LIFE CYCLE IMPACT ASSESSMENT

By compiling all the aforementioned data and applying the appropriate characterisation factors, an initial estimation of Dublin Array's GHG emissions was calculated.

4.1 CHARACTERISATION FACTORS

Three sources were used to estimate the unit impacts of the different flows required across the lifetime model of the wind farm, as follows:

- The UK Government's "conversion factors for company reporting of greenhouse gas emissions" was used for some energy unit conversions and waste management processes). These are themselves based on the Fifth Assessment Report (AR5) from the International Panel on Climate Change (IPCC);
- The Royal Institution of Chartered Surveyors (RICS) Whole life carbon assessment for the built environment professional standard 2nd edition (2023) was used for a characterisation factor for construction; and
- The University of Bath's Inventory of Carbon and Energy (Hammond and Jones, 2008) dataset was used for a characterisation factor for asphalt.

All the remaining characterisation factors were taken from the Ecoinvent database (Ecoinvent, 2016). To ensure consistency with the UK Government's data, the method used was the same IPCC2013 data from the AR5 report.

This selection of sources for the characterisation factors means that all impacts are reported as emissions of greenhouse gases that contribute to climate change, considered over a 100-year period, relative to the impact of carbon dioxide i.e. in units of weight of Carbon Dioxide equivalents (CO_2eq).

4.2 CLIMATE CHANGE RESULTS

By applying the selected characterisation factors to the inventory of flows collected during the data gathering process and summarising them by life cycle stage, the initial results were compiled.

Given the sixty potential scenarios (3 main array scenarios, five WTG foundation sub scenarios and four OSP foundation sub scenarios) for the manufacturing and freight stages, there are also sixty potential scenarios for the climate change results. Therefore, the same method was used here; only the best-case (lowest emissions) and worst-case (highest emissions) combinations of options are presented for each scenario. These scenarios are detailed in Table 4-1. The initial results are presented in Table 4-2.

Table 4-1 Details of least impact and greatest impact foundation option combinations for each scenario

Scenario	Layout option A	Layout option B	Layout option C
Best-case	WTG option 4 OSP option 3	WTG option 4 OSP option 3	WTG option 4 OSP option 3
Worst-case	WTG option 3 OSP option 4	WTG option 3 OSP option 4	WTG option 3 OSP option 4

Table 4-2 Climate change impact (in tCO_2eq) contributions from each life cycle stage

Life Cycle Stage	Layout option A (best-case)	Layout option A (worst-case)	Layout option B (best-case)	Layout option B (worst-case)	Layout option C (best-case)	Layout option C (worst-case)
Raw materials	1,850,000	2,130,000	1,730,000	1,990,000	1,860,000	2,090,000
Manufacture	386,000	940,000	357,000	908,000	368,000	894,000
Transport	83,900	73,900	84,900	71,900	88,400	73,700
Installation	58,900		53,800		48,800	
Use	107,000		96,500		83,700	
End of life	0		0		0	
Total	**2,490,000**	**3,310,000**	**2,320,000**	**3,120,000**	**2,440,000**	**3,190,000**

The results indicate that the materials used for Dublin Array, along with their manufacturing, contribute the most significantly to the overall impacts, accounting for 90% to 94% across the various scenarios. In comparison, although vessel movements throughout the project's lifetime involve fuel consumption, their impact remains relatively minor, contributing only 2-4% to the overall impacts.

Table 4-2 highlights that the main difference between the best-case and worst-case impacts of each scenario is primarily due to the manufacturing burden, as illustrated in Figure 4-1. This difference arises because some WTG foundation options require large quantities of concrete, while others rely heavily on steel. Since concrete has no additional manufacturing burden, while steel does, the manufacturing impact varies significantly between scenarios that use concrete-based versus steel-based WTG foundations.

Figure 4-1 Climate change impact (in t CO_2eq) contributions from each life cycle stage

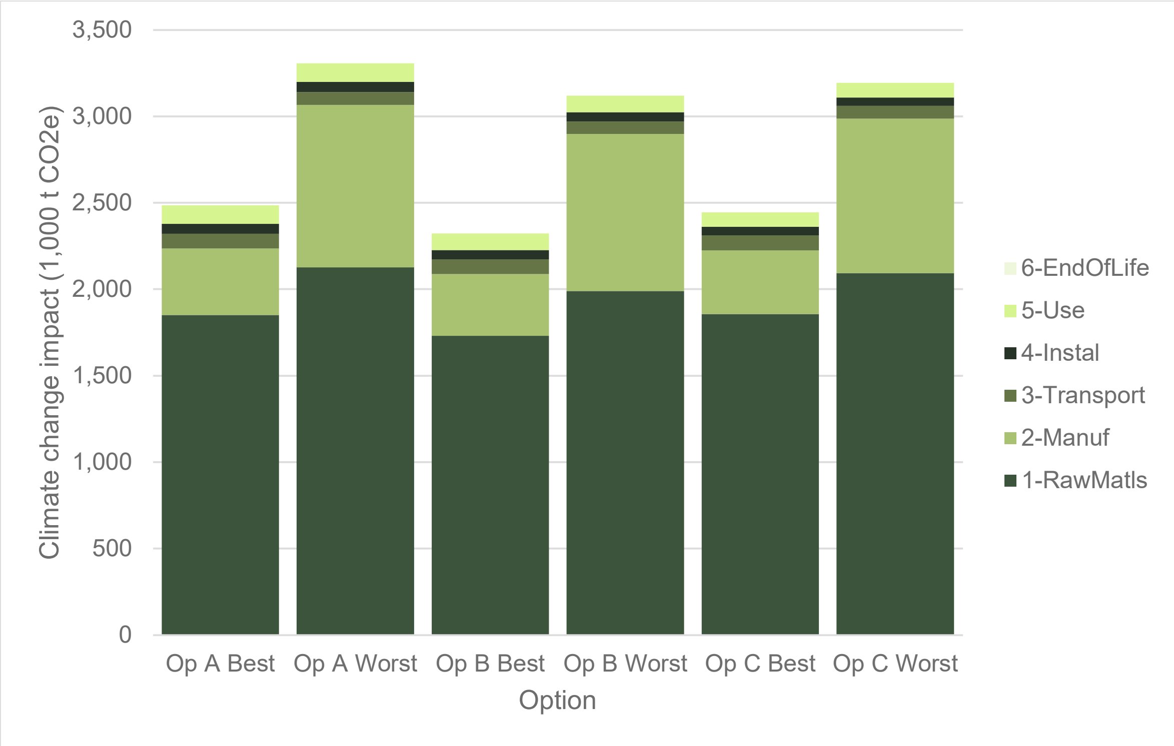


Table 4-2 also shows that 45 18 MW WTGs (Option B) has a smaller carbon impact than the other two Options, in both its best-case and worst-case scenario.

The findings in Table 4-1 show that the combination of foundation options resulting in the lowest carbon impact across all three scenarios is WTG Foundation Option 4 (jacket & pin-pile and grout, 4 leg structure), paired with OSP Foundation Option 3 (monopile & grout). Conversely, the highest carbon impact is observed with the combination of WTG Foundation Option 3 (jacket & pin-pile and steel, 4 leg structure) and OSP Foundation Option 4 (jacket & grout).

4.3 CARBON INTENSITY CALCULATION

Looking at the scenario option with the greatest carbon impact (Option A with WTG Foundation Option 3 and OSP Foundation Option 4), Dublin Array is estimated to emit 3.31 million tonnes (Mt) CO_2eq over its lifetime. However, this should be evaluated in the context of the electricity it will generate. While there are uncertainties regarding the exact amount of electricity produced (explored further in Section 4.6), it is estimated that its annual production levels might be of the order of 2,957 GWh/yr. This estimate is based on three different scenarios for WTG sizes and numbers, applying a 45% load factor specific to the East coast of Ireland as cited in Energy Ireland's 2023 report (Energy Ireland, 2023). This figure aligns with the median of sources that report a consistent load factor range of 40-50% for Ireland. Wind Energy Ireland assumes an offshore wind capacity factor of 50% (Wind Energy Ireland, 2023), while SSE Renewables assumes a 40% load factor (SSE Renewables, 2020).

Ultimately the number of WTGs chosen could be one of three potential options, affecting annual production levels, and, correspondingly, the embedded carbon emissions. At the estimated production rate, Dublin Array is expected to generate 103,000 GWh of electricity over a 35-year operational period.

The option with the greatest carbon impact (Option A, involving WTG Foundation Option 3 and OSP Foundation Option 4) results in a total estimated carbon emission of 3.31 Mt CO_2eq over the project's lifetime. Given the expected electricity generation of 103,000 GWh over 35 years, this equates to an average carbon intensity of 32.0 grams of CO_2eq per kilowatt-hour (g CO_2eq/kWh). This calculation is represented by the equation:

$$Carbon\ Intensity = \frac{Lifetime\ carbon\ emissions}{Lifetime\ electricity\ generated} = \frac{3.31\ \mathrm{Mt}}{103{,}000\ \mathrm{GWh}} = 32.0g\ CO2e/kWh$$

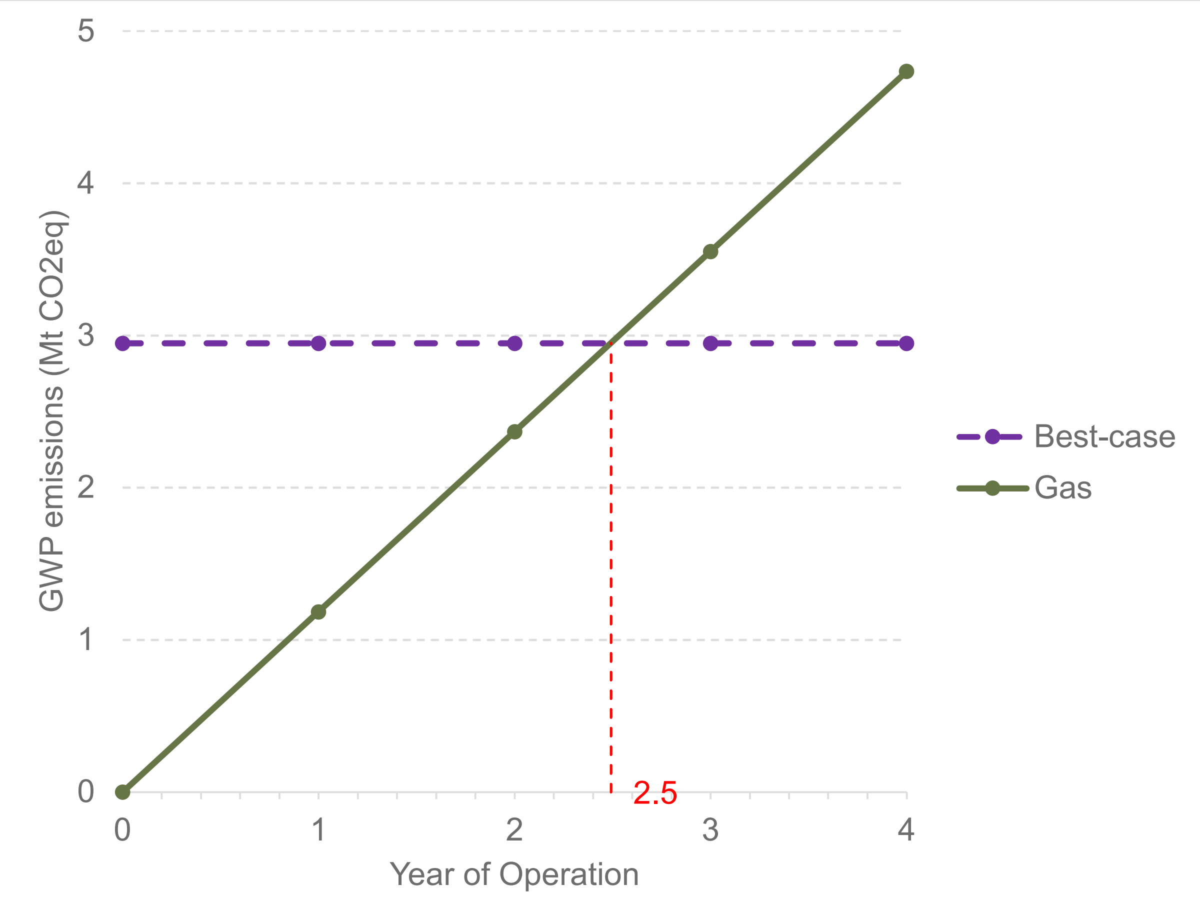
For the option with the lowest carbon impact (Option B with WTG Foundation Option 4 and OSP Foundation Option 3 using the Energy Ireland load factor), annual electricity production is estimated at 3,193 GWh, with a total carbon footprint of 2.32 Mt CO_2eq. This results in a carbon intensity of 20.8 g CO_2eq/kWh.

4.4 PAY BACK PERIOD

It is standard practice to calculate a wind farm's carbon "pay-back" period – which represents the time required for the carbon emissions from its construction to be offset by the reduced carbon emissions of the electricity it generates. To perform this calculation, it is necessary to determine how the electricity would otherwise be generated. Typically, the additional electricity from a WTG does not replace other renewable sources, but instead displaces the generation technology that would have been "the last to be turned on" – referred to as the "marginal mix". In Ireland, the marginal mix for the foreseeable future is expected to be gas, specifically Combined Cycle Gas Turbine (CCGT), with a carbon intensity of approximately 371 g CO_2eq/kWh (DUKES, 2023).

By multiplying this carbon intensity by the 2,957 GWh of electricity generated annually (based on the option with the greatest carbon impact), it is estimated that equivalent CCGT sourced electricity would produce approximately 1.1 Mt CO_2eq per year. Figure 4-2 illustrates the cumulative emissions from CCGT electricity over the first four years of operation compared to the project's total lifetime emissions. Based on these assumptions, Dublin Array is expected to achieve carbon payback within 3.0 years, after which it would provide annual carbon savings for the remainder of its operational life.

Figure 4-2 GWP 'Pay Back' Analysis for the worst-case scenario (Option A with WTG foundation option 3 and OSP foundation option 4)

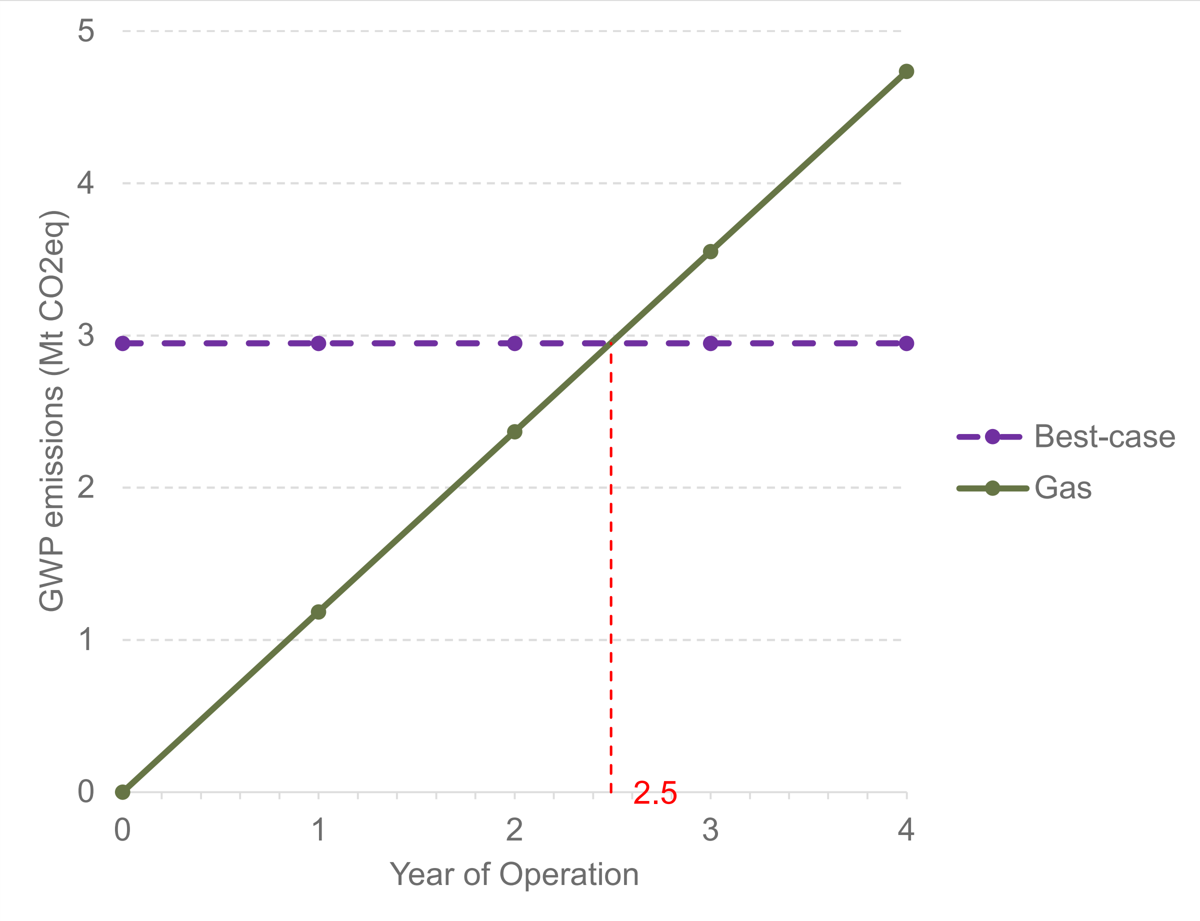


Another perspective is to determine the cumulative carbon impact over 35 years of generating electricity from the alternative source (CCGT). For Option A, this cumulative impact is approximately 38 Mt CO_2eq, which is almost 12 times greater than the total lifetime carbon emissions of Dublin Array's highest impact scenario.

Overall, even under the highest impact scenario, Dublin Array is expected to yield significant net benefits in terms of lifetime emission reductions compared to baseline scenarios, with an estimated net benefit of 35 Mt CO_2eq when assuming CCGT sourced electricity as the alternative.

In the scenario with the lowest carbon impact, the use of differently sized and fewer WTGs, combined with the alternative WTG and OSP foundation types, results in a faster carbon payback period, as shown in in Figure 4-3. Under these conditions, Dublin Array would achieve carbon payback in 2.0 years and continue to provide deliver annual carbon savings throughout its operational life.

Figure 4-3 GWP 'Pay-back' Analysis for the best-case scenario (Option B with WTG foundation option 4 and OSP foundation option 3)



Operating for 35 years, with a higher annual power generation of 3,261 GWh, the cumulative emissions of the alternative electricity source (CCGT) would be 41 Mt CO_2eq, almost 18 times the lifetime carbon impacts of Dublin Array.

Overall, the project's best-case scenario is also deemed to have a significant net benefit regarding lifetime emission reduction compared to the project baseline scenarios, with a net benefit of 39 Mt TCO_2eq assuming CCGT derived electricity.

4.5 SENSITIVITY TESTING

It is good practice to explore how the results might depend on important uncertainties or assumptions in the underlying data. In this instance, the results are quite conclusive that Dublin Array (best- and worst-case) is (~12-18 times) better than the likely counterfactual electricity alternative. However, it is still instructive to explore how much the values might change, based on changes in the underlying data. In this section, two further checks are performed below.

4.6 ANNUAL ELECTRICITY PRODUCTION

As discussed in Section 4.3, there is some uncertainty surrounding the amount of electricity that Dublin Array might produce annually, with initial estimates being 3,020 and 3,261 GWh/yr for the highest and lowest impact scenarios, respectively. These estimates are based on an assumed load factor 45%. To assess the potential variation in this assumption, alternative scenarios were developed with different load factors, exploring both optimistic and conservative estimates.

Alternative load factors of 40% (based on a load factor for Irish wind energy stated by SSE Renewables; SSE Renewables, 2020) and 50% (based on a load factor for Irish wind energy stated by Wind Energy Ireland; Wind Energy Ireland, 2023) were selected for analysis. Reducing the assumed load factor from 45% to 40% extends the carbon payback period to 3.4 years for the highest impact scenario, indicating minimal impact on the overall outcome. To explore a more extreme possibility, the annual electricity production was halved to 1,478 GWh/yr. Even with this significant reduction, Dublin Array would still achieve carbon payback after 6.0 years of operation.

These reduced load factor and electricity production scenarios were also applied to the lowest impact scenario. Reducing the load factor to 40% increases the payback period to 2.2 years, again showing a limited effect on results. Halving the annual electricity production to 1,597 GWh/yr results in a carbon payback period of 3.9 years.

Conversely, evaluating a higher load factor for Dublin Array of 50% for both scenarios shortened the carbon payback period to 2.7 years for the highest impact scenario and 1.8 years for the lowest impact scenario.

Overall, Dublin Array's GHG results are shown to be relatively robust to uncertainties in electricity generation. In all cases, carbon payback is achieved within six years of operation or less, confirming the resilience of the project's carbon payback performance.

4.7 CONSTRUCTION BURDENS

Given the uncertainties surrounding the specific materials to be used for Dublin Array, an analysis was conducted to assess how the results would change if the material burdens, including those for manufacturing, transport, and installation, were double from the original estimates. In this scenario, Dublin Array (in the highest impact scenario) would take 5.9 years to offset its carbon burden. In the lowest impact scenario, Dublin Array would require 3.8 years to achieve carbon payback. These results reinforce the significant carbon benefits of Dublin Array, even under assumptions of increased material impacts.

5.0 SUMMARY

This study has performed an LCA for Dublin Array, encompassing the entire lifecycle from the production of the raw materials used for construction, to the recycling or disposal of those same materials after decommissioning at the end of its operational life.

For an assumed 35-year operational period with 50 15 MW WTGs, a jacket & pin-pile and steel, 4 leg structure WTG foundation system, and a jacket & grout OSP foundation system, the estimated GHG emissions are 3.31 Mt CO_2eq (representing the highest impact scenario). Dublin Array is expected to generate 2,957 GWh of electricity annually, resulting in a carbon intensity of approximately 32.0g CO_2eq/kWh.

For an assumed 35-year operational period with 45 18 MW WTGs, a jacket & pin-pile and grout, 4 leg structure WTG foundation system, and a monopile & grout OSP foundation system, the estimated GHG emissions are 2.32 Mt CO_2eq (representing the lowest impact scenario). Dublin Array is expected to produce 3,193 GWh of electricity annually, leading to a carbon intensity of approximately 20.8g CO_2eq/kWh.

Gas is the dominant energy source in the Irish power generation mix and is therefore expected to be the energy source that Dublin Array is replacing. When compared to the alternative of generating electricity using gas (CCGT), which has a carbon intensity of 371 g

CO_2eq/kWh), Dublin Array is projected to offset the embedded emissions from construction within two years for the lowest impact scenario, and three years for the highest impact scenario.

6.0 REFERENCES

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