Awel y Môr Offshore Wind Farm

Life Cycle Assessment for the Awel y Môr Offshore Windfarm

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LIFE CYCLE ASSESSMENT FOR THE AWEL Y MÔR OFFSHORE WINDFARM

Prepared for: Awel y Môr Offshore
Wind Farm Limited

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1.0 Introduction

Awel y Môr Offshore Wind Farm Limited (the Applicant) submitted an application for a Development Consent Order (DCO) to the Planning Inspectorate (PINS) for the Awel y Môr Offshore Wind Farm (AyM) on 20 April 2022. AyM was accepted for consideration by PINS on 18 May 2022. The Secretary of State (SoS) for Levelling Up, Housing and Communities subsequently appointed a panel of Planning Inspectors to examine the application, known as the Examining Authority (ExA). This life cycle assessment has been produced during the examination phase of AyM, and is provided as part of the Applicant's submission at Deadline 5 in response to Question 0.9 within the first round of questions from the ExA:

'Carbon Assessment

Draft NPS EN-1 section 5.3.4 sets out that all proposals for energy infrastructure projects should include a carbon assessment as part of their ES, along with the type of information which should be included within the assessment. Section 4.2 of draft NPS EN-1 makes reference to the Infrastructure Planning (Environmental Impact Assessment) Regulations 2017 which refer to, amongst other things, climate. In addition, during consultation for the redetermination of the Norfolk Vanguard project, the Secretary of State (SoS) highlighted the desirability of a carbon footprint and impact assessment that considered embedded carbon and greenhouse gases from the extraction, refinement and manufacture of elements of the project, along with the emissions from the construction (including trenching and excavation of arable land and loss of greenhouse gas absorption capacity from farming, plants and trees), operation, maintenance and decommissioning.

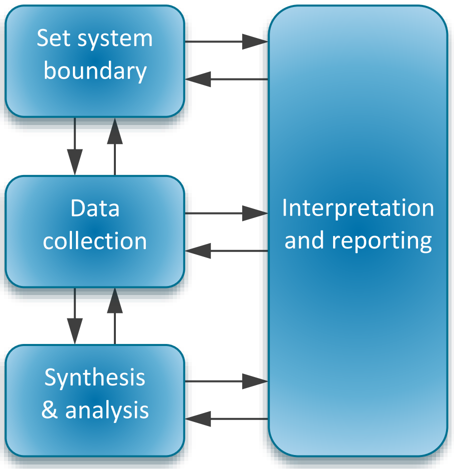
Could the Applicant signpost any assessment work of this nature that has been undertaken and does the Applicant intend to provide anything further in this respect? If so, by what deadline will be this be submitted by?'

The Applicant commissioned SLR Consulting Limited (SLR) to perform a life cycle assessment (LCA) of the environmental impacts of AyM, the findings of which are presented in this report.

LCAs are undertaken by SLR in accordance with the method outlined by the International Standards Organisation in their series ISO 14040-44. This method features the four-step process shown schematically beside.

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;
- Interpreting and reporting the results.



2.0 Setting the goal and scope for analysis

The first step was to agree the goal and scope for the analysis, defining what would be within the scope of study and what not. The topics and the decisions agreed are summarised below:

Study goal:	To identify the life cycle climate change impacts of the proposed AyM in Wales, in comparison with how its electricity might otherwise be generated.
Scenarios:	Two scenarios were considered, both involving the construction, operation and ultimate decommissioning of AyM (wind turbine generators plus all supporting onshore and offshore

infrastructure), but one featured 50 smaller wind turbine generators, whilst the other considered 34 large wind turbine generators (in line with the wind turbine generator scenarios considered within the Environmental Statement).

Time: AyM is expected to operate for at least 25 years. This means that impacts arising from its decommissioning, as well as those from the later years of its operation, are subject to some level of uncertainty. The approach taken to deal with this uncertainty has generally been to assume the worst case. This is explained in more detail in the relevant sections below.

Geography: As already noted, AyM will be located off the coast of North Wales. Accordingly, the study was founded on operations in the UK, but included freight impacts to get materials and components to Wales from their anticipated points of origin, around the globe.

Functional unit: This is the basis by which the scenarios are compared. Initial calculations sought to estimate the lifetime impacts of the entire windfarm, for each turbine scenario. For the purposes of comparing these to the alternative means of electricity generation, impacts are reduced to an average carbon intensity of generation, in g CO_2eq/kWh.

Impact criteria: This is a single criterion study, examining only global warming potential impacts, on a 100-year period (GWP100). More details are provided in Section 4.1.

Data sources: A key scope consideration concerns from where the underlying data will be sourced. Analysis is more accurate if we use specific (“primary”) data direct from the technology provider(s), rather than generic (“secondary”) data from literature, but primary data involves more resources to collect, check and process. Furthermore, much of the data collected inevitably turns out to be relatively unimportant, making insignificant contributions to the final totals. The data sources used in this study are discussed in the next section, and reveal that much had to be taken from secondary sources, as the project has not yet reached the detailed design stage.

Life-cycle stages: An **attributional approach** was deemed appropriate for this study, looking at AyM’s complete impacts across its lifetime.

A **systems expansion** approach was adopted to account for the benefits of the electricity generated over its lifetime. These were expected to displace UK marginal electricity, expected to continue to be Combined Cycle Gas Turbine (CCGT) for years to come. A sensitivity was also performed against the BEIS “all non-renewables” technology mix.

The **“avoided burden” approach** was adopted to account for the benefits of recycled content and recyclability at the end of life. Simply put, this means that AyM could be credited with the benefits of sending materials to recycling at end of life, but would have to assume all incoming materials were virgin materials (to avoid double-counting).

Platform: Calculations were performed in MS Excel®.

GHG absorption: AyM will result in the permanent loss of 5ha of above ground vegetation as a result of the onshore substation. Although there would also be temporary loss of vegetation as a result of construction activity (up to 48ha assuming a 12km cable corridor that is 40m wide), this combined with the permanent loss of 5ha represents a negligible loss of absorption capacity in comparison to climate change impact (in t CO_2eq) contributions from each of the project’s life cycle stages[1]. Therefore, in line with similar assessments undertaken for other DCO schemes including Hornsea 4 and Norfolk Vanguard offshore wind farms, GHG emissions associated with the loss of GHG absorption capacity are not considered further in the assessment. As noted within the outline Landscape and Ecology Management Plan submitted with the application, the Applicant has committed to plant woodland around the proposed substation and in addition

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[1] Cursory calculations by SLR estimated the lifetime sequestered carbon might be less than 200 tonnes.

replace each tree lost as a result of the scheme with three new trees. Although these actions would further offset carbon emissions from construction of the project, these represent a negligible amount that is not incorporated within the assessment.

3.0 Data collection

Data collection is the most challenging aspect of an LCA study. Looking to model the entire burdens of a wind farm before, during and after an assumed 25 years of operation is a challenge, and involves collecting data from the across six key stages of the life cycle:

1. Raw Materials
2. Manufacturing
3. Installation
4. Operation
5. Freight
6. End of Life

The rest of this section provides more detail on the data collected for each of the six stages. The primary source of data for the project was information provided by the Applicant regarding the planning design and construction of the windfarm that has also been used to inform the Environmental Impact Assessment (EIA) for AyM.

3.1 Raw Materials

'Raw Materials' refers to the environmental impacts embedded in the materials of construction of the windfarm (but not their fabrication or installation, which are covered in later stages). The Applicant provided details of the materials that would be needed for (for example) the onshore export cables and the substation. This information was supported with data provided in a bespoke template, on the amounts of materials in the construction of the turbines and their foundations. The main components and weights are listed in Table 2 below. For the small and large turbines and the offshore platform, the number of those items are provided in the column headings, and the weights are per item.

3.2 Manufacturing

Some of the burdens in the above section simply cover the production of, for example, a tonne of low-alloyed steel. Further emissions are embedded during the manufacturing of the windfarm components from those materials. It is not practical to gather actual manufacturing for all components, and of course many would make a negligible contribution to the final impacts, but it was deemed appropriate to estimate the manufacturing burdens for some of the materials, as detailed in Table 1.

Table 1: Materials weights (in tonnes) separately assigned manufacturing burdens

Material	Small Turbines	Large Turbines	Offshore Substation Platforms (OSPs)	Other
Stainless steel	4,100	3,400	n/a	n/a
Steel	178,350	156,672	1,382	5,900
Reinforcing steel	n/a	n/a	5,000	667
HDPE	n/a	n/a	n/a	683
Nylon	n/a	n/a	n/a	77

Table 2: Bill of Materials for main components in AyM

Description	Detail	Units	Small (50)	Large (34)	OSP (2)	Other	Notes
Wind Turbines							
Monopile[2]	Steel	t	1,600	2,200	n/a	n/a	Per turbine
Gravity Base Foundation[2]	Concrete	t	5,400	6,300	n/a	n/a	Per turbine
Gravity Base Foundation[2]	Steel rebar and ancillary steel works	t	600	700	n/a	n/a	Per turbine
Fibreglass (epoxy)		t	226	277	n/a	n/a	Per turbine
Carbon Fibre (epoxy)		t	23	28	n/a	n/a	Per turbine
Cast Iron		t	82	100	n/a	n/a	Per turbine
Steel		t	1,967	2,408	n/a	n/a	Per turbine
Copper		t	173	212	n/a	n/a	Per turbine
CroMag Steel		t	82	100	n/a	n/a	Per turbine
Polymer		t	1	1	n/a	n/a	Per turbine
Neodymium		t	18	22	n/a	n/a	Per turbine
Ester Oil		t	9	11	n/a	n/a	Per turbine
Cables							
Array Cable	Copper wire core	kg/km	n/a	n/a	n/a	28,800	123.8km required
Array Cable	Steel cable armour	kg/km	n/a	n/a	n/a	18,280	123.8km required
Array Cable	Plastic fillers, tapes, insulation, yarn	kg/km	n/a	n/a	n/a	12,280	123.8km required
Export Cable	Copper wire core	kg/km	n/a	n/a	n/a	55,480	79.6km required
Export Cable	Steel cable armour	kg/km	n/a	n/a	n/a	29,559	79.6km required
Export Cable	Plastic fillers, tapes, insulation, yarn	kg/km	n/a	n/a	n/a	31,460	79.6km required
Offshore Platform							
OSP Topside - Equipment	Transformer and other electrical Infrastructure	t	n/a	n/a	520	n/a	Per OSP
OSP Topside - Structural Steel		t	n/a	n/a	691	n/a	Per OSP
OSP Topside - Insulation		t	n/a	n/a	35	n/a	Per OSP

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[2] It should be noted that although monopiles and gravity base foundations are included in the Design Envelope, the final design will select one of these scenarios, and therefore they should not be considered additive. The results showed that the monopile design had the higher impact, so this was chosen for the modelling.

Description	Detail	Units	Small (50)	Large (34)	OSP (2)	Other	Notes
OSP Topside - Cables	including ducts, trays and supports	t	n/a	n/a	110		Per OSP
OSP Foundation - Steel		t	n/a	n/a	2,500		Per OSP
Onshore Substation							
Onshore Substation	Concrete	m^3	n/a	n/a	n/a	5,300	
Onshore Substation	Imported Engineered Fill	m^3	n/a	n/a	n/a	95,550	
Onshore Substation	Fencing	m^3	n/a	n/a	n/a	950	
Onshore Substation	Reinforcement	t	n/a	n/a	n/a	600	
Onshore Substation	Chippings	m^3	n/a	n/a	n/a	3,600	
Onshore Substation	Drainage	m^3	n/a	n/a	n/a	2,880	
Onshore Substation	Structural Steel	t	n/a	n/a	n/a	1,200	
Onshore Substation	Cladding	m^2	n/a	n/a	n/a	5,850	
Onshore Substation	Bituminous road	m^3	n/a	n/a	n/a	6,500	

3.3 Installation

Installation covers the extensive effort associated with constructing AyM. The Applicant provided details of the anticipated numbers of journeys that will be required by a range of vessels, as shown in Table 3.

Table 3: Anticipated construction vessel movements

Parameter	Small Turbines	Large Turbines
Construction vessel movements	*3,436*	*3,399*
Materials Transport Construction	*96*	*66*
Total construction ship movements	3,532	3,465
Helicopter movements	1,060	1,060
Truck movements	2,842	2,842

The Applicant also provided distances from the site to a range of possible ports that might host the vessels, both for the construction and for the later operational phase. The project will select port locations that are as close as practical to the site. The median values of the possible port locations are estimated as follows:

- Assumed distance travel per vessel movement during construction: 157km (return journey).
- Assumed distance travel per vessel movement during operation: 90km (return journey).
- Assumed distance for truck movements: 25km.

3.4 Operation

During the operation of AyM, the Applicant estimates that the materials listed in Table 4 will be required every year, for each of the items (e.g. each small turbine will require 838l of grease, each year).

Table 4: Anticipated levels of material consumption during operational phase (annual, per item)

Description	Units	Small Turbines (50)	Large Turbines (34)	OSP (1)
Grease	l	838	1,317	n/a
Hydraulic oil	l	1,583	2,487	n/a
Gear oil	l	3,108	4,883	n/a
Nitrogen	l	101,479	159,467	n/a
Transformer silicon/ester oil	l	11,358	17,849	340,000
Diesel fuel	l	1,000	1,000	20,000
SF6	kg	180	180	5,000
Glycol/Coolants	l	21,972	34,527	n/a

Description	Units	Small Turbines (50)	Large Turbines (34)	OSP (1)
Batteries	kg	3,000	4,000	350,000
Grey water	l	n/a	n/a	5,000
Black water	l	n/a	n/a	3,000

The operation of the windfarm will also require continued annual vehicle movements, estimated to be as presented in Table 5.

Table 5: Anticipated yearly operational vessel movements

Parameter	Small Turbines	Large Turbines
Total O&M ship movements	1,208	1,198
Helicopter movements	200	120

3.5 Freight

In addition to the vessel movements already described, the calculations take into account the freight that will bring the construction and maintenance materials to the local area, and (at end of life) remove the materials for recycling or disposal. The estimated total additional amounts of freight movements required, in thousands of tonne-kilometres (ktkm) by road and by sea, are presented in Table 6.

Table 6: Anticipated additional freight requirements

	Small turbines		Large turbines	
	Road ktkm	Ship ktkm	Road ktkm	Ship ktkm
Raw Materials	13,411	1,427,509	13,032	1,314,740
Manufacturing	n/a	n/a	n/a	n/a
Construction	n/a	n/a	n/a	n/a
Operation	2,777	n/a	2,917	n/a
End of Life	13,788	n/a	13,542	n/a

3.6 End of Life

It is difficult to be certain what will happen to AyM’s materials at end of life, simply because this will not occur for at least another 25 years, by which time, the state of available technology may be very different. For the purposes of the current calculations, it has been assumed that all of the iron, steel and copper materials in the windfarm will be fully recycled. Under the scope set out for the calculations, these materials are given a credit for the virgin materials they will offset (less the impact of creating new recycled raw materials from them).

For the purposes of this assessment, the calculations then go to assume that all other materials will be removed from site, with 50% being recycled and 50% being disposed, all locally near the AyM site.

The Applicant is also charged with the effort required to move all of these materials at end of life, with a simple (and likely pessimistic) assumption made that the same number of movements will be required for decommissioning as had been required during construction.

4.0 Life Cycle Impact Assessment

By bringing all the above information, and applying appropriate characterisation factors, a first estimation was determined.

4.1 Characterisation factors

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

1. For some factors, it was necessary to use the UK Government's "conversion factors for company reporting of greenhouse gas emissions". These are themselves based on the fourth assessment report (AR4) from the International Panel on Climate Change (IPCC).
2. For a couple of factors, the University of Bath's Inventory of Carbon and Energy (ICE) dataset was used, from 10th November 2019.
3. However, the bulk of the characterisation factors were taken from the ecoinvent database. To ensure consistency with the UK Government's data, the method used was the same IPCC2007 data from the AR4 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, so in units of weight of carbon dioxide equivalents.

4.2 Climate Change Results

Applying the chosen characterisation to the inventory of flows generated during the data collection, and summing by life cycle stage, led to the compilation of the initial results presented in Table 7 below.

Table 7: Climate change impact (in t CO_2eq) contributions from each life cycle stage

Life cycle stage	Small turbines	Large turbines
Turbine materials	615,000	528,000
Other materials	126,500	126,500
Manufacturing	382,500	339,000
Construction	16,500	15,000
Operation (25 years)	302,000	297,000
Freight	17,500	16,000
End of Life	-375,000	-331,500
Total	**1,085,000**	**990,000**

The calculations conclude that the installation of more, smaller turbines leads to a total impact across the lifetime of AyM that is about 10% higher than using a smaller number of larger turbines.

The results also show that AyM's materials (and their manufacture) make the largest contribution to the overall impacts.

4.3 Carbon Intensity Calculation

Assuming an indicative generation capacity of 576MW , it is estimated that AyM will generate around 2,255GWh of electricity every year. Over an operational lifetime of 25 years, assuming that the outputs remain constant, this would amount to 56,365GWh. Dividing the total climate change impact figures in Table 7 by this value gives the average carbon intensity of the electricity over AyM's lifetime:

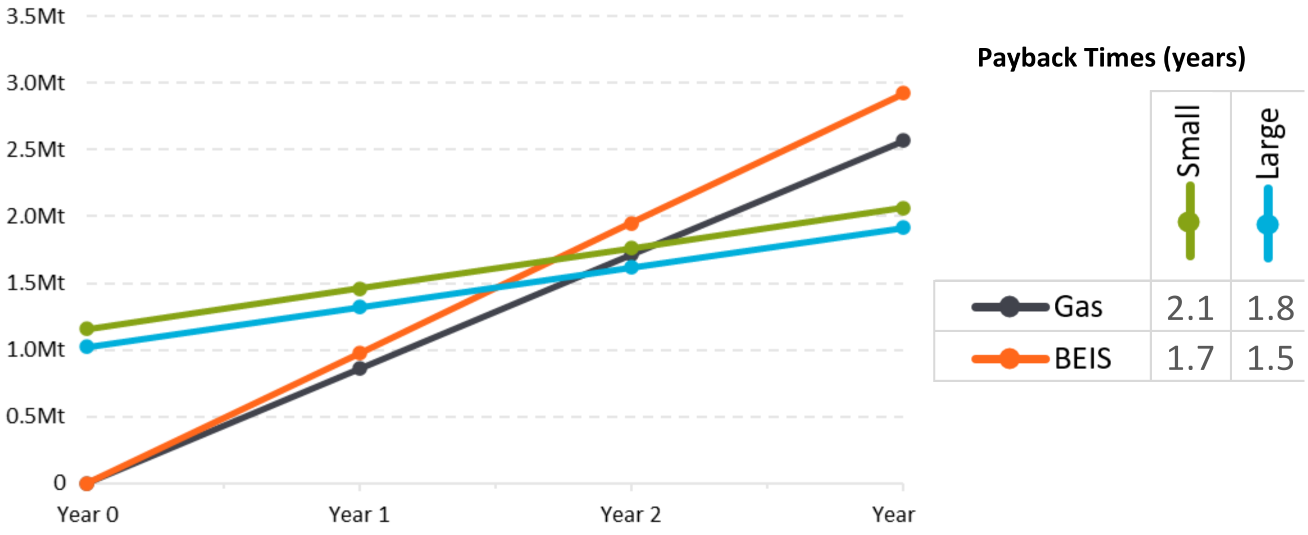
- **Carbon intensity for small turbines = 1,085,000 / 56,365 = 19.2 t CO_2eq/GWh = 19.2g/kWh**
- **Carbon intensity for large turbines = 990,000 / 56,365 = 17.6 t CO_2eq/GWh = 17.6g/kWh**

4.4 Pay Back Period

It is common practice to determine the project's "pay-back" period – that is, how long into the lifetime of the windfarm before the carbon emissions associated with its construction are counter-acted by the lower carbon emissions of the electricity it generates. In order to perform this calculation, it is necessary to determine how the electricity would otherwise be generated. It is accepted that, when the windfarm comes online, its additional electricity will not replace nuclear or other renewable generating technologies. Rather, it will displace whatever electricity generating technology would have been "the last to be turned on" – not the grid mix, therefore, but the so-called "marginal mix". In the UK, for the foreseeable future, the marginal mix technology is CCGT, which has a carbon intensity of about 380g/kWh. Alternatively, RenewableUK recommends[3] using BEIS's "all non-renewable fuels" emission factor, which was 432g/kWh in July 2022.

Multiplying these intensities by the 2,255GWh of electricity generated each year reveals that the counterfactual-sourced electricity would be responsible for 857kt CO_2eq (CCGT) or 974kt CO_2eq (BEIS) each year. The cumulative impact of this over the first three years of operation is compared in Figure 1 with the equivalent data for the two windfarm scenarios, which have a high "year 0" impact associated with construction but then much lower annual emissions thereafter. As the key shows, the windfarm scenarios achieve payback in around two years.

Figure 1: Cumulative carbon emissions from windfarm scenarios versus counterfactuals, and payback times



Payback Times (years)

	Small	Large
Gas	2.1	1.8
BEIS	1.7	1.5

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[3] See [redacted]

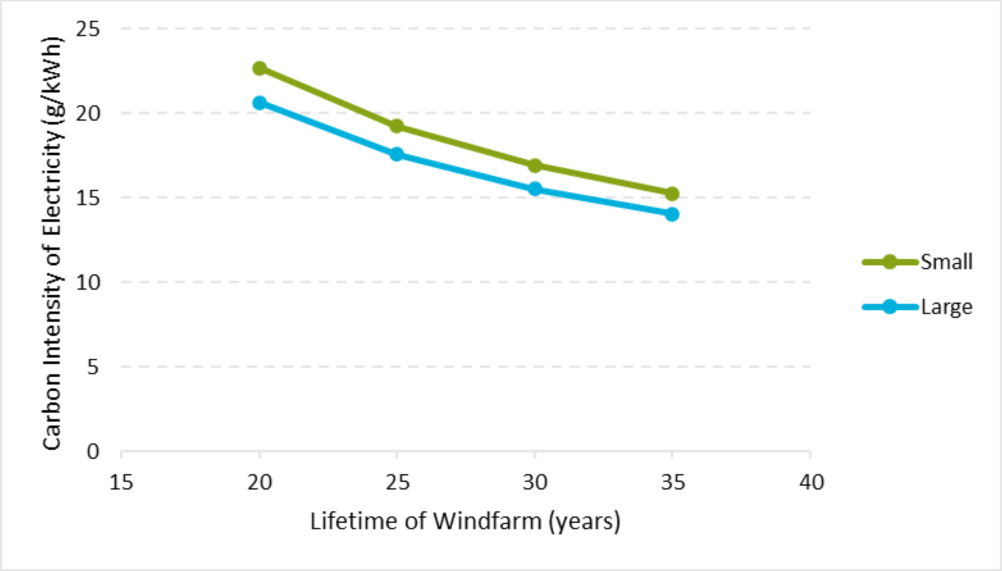
4.5 Sensitivity Testing

As done in Figure 1 above, it is good practice to explore how the results might depend on important uncertainties or assumptions in the underlying data. Two further checks are performed below.

4.5.1 Lifetime of AyM

The first assumption examined in this modelling is the lifetime of AyM, which might exceed 25 years. Because the windfarm has relatively low impacts during its operational phase, its average carbon intensity reduces as the expected lifetime increases. As Figure 2 below demonstrates, the average carbon intensities of electricity for the large and small turbines fall to 14.1 and 15.3g/kWh respectively if the windfarm operates for 35 years.

Figure 2: Plot showing decrease in carbon intensity of electricity as lifetime of windfarm increases

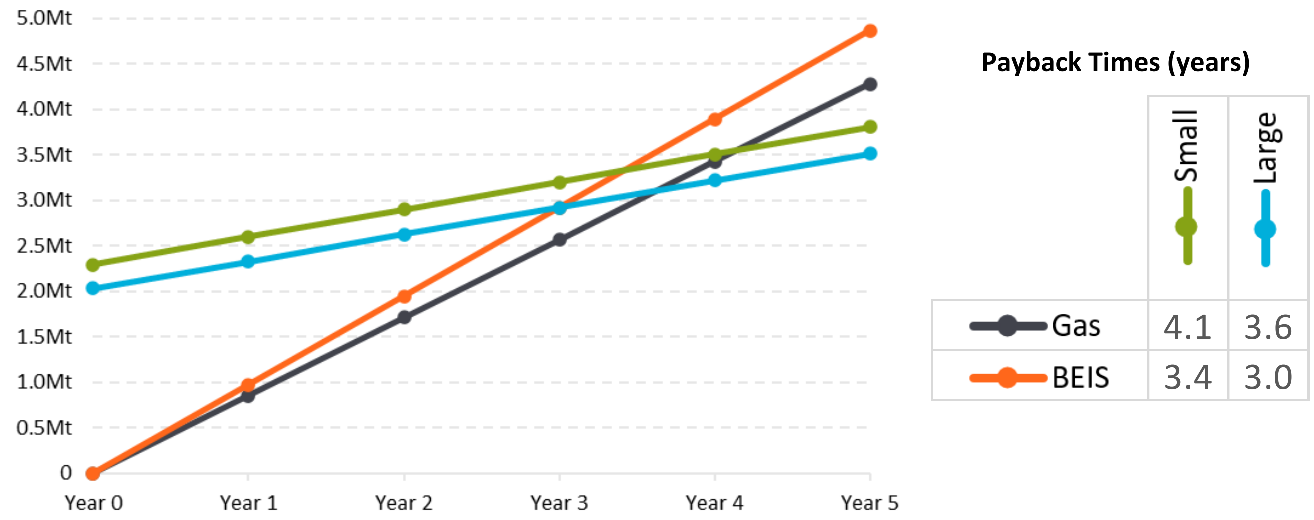


4.6 Construction Burdens

A second form of sensitivity testing, known as "extreme value testing", involves using drastically different input data to explore how the results change. As there are some uncertainties about the exact bill of materials details for the windfarm, it was decided to explore how the results would change if the construction burdens were double the originally calculated values.

The figures were fed into the same pay-back analysis versus CCGT and BEIS "all non-renewables" presented in Figure 1 above. With double the construction burdens, the windfarms understandably take longer to pay-back their carbon impacts, but still achieve pay-back within about four years, as shown in Figure 3.

Figure 3: Pay-back analysis with double construction burdens for windfarms



Payback Times (years)

	Small	Large
Gas	4.1	3.6
BEIS	3.4	3.0

5.0 Summary

This study has performed a life cycle assessment of the proposed AyM scheme. The scope considered impacts across the whole life cycle, from the production of the raw materials used to construct the facility, all the way through to the recycling or disposal of those same materials after decommissioning at the end of its lifetime.

The net greenhouse gas emissions across an assumed 25-year lifetime operation are estimated to be 0.99 to 1.09Mt CO_2eq, depending on whether 34 large or 50 smaller wind turbine generators are deployed. AyM is expected to produce 2,255GWh of electricity each year, meaning the carbon intensity of the electricity generated will be 17.6 or 19.2g CO_2eq/kWh.

When compared with the alternative of generating the electricity by gas CCGT (with a carbon intensity of 380g CO_2eq/kWh) or BEIS's "all non-renewables" factor of 432g CO_2eq/kWh, the windfarm will pay-back the embedded emissions in its construction in around two years.

Sensitivity testing has showed that this figure rises to within five years if the construction burdens turned out to be double what has been estimated. This is of course thought to be unlikely, but demonstrates that the windfarm will make a positive contribution towards combating climate change, whatever the exact burdens are likely to be.

A second sensitivity test demonstrated that the carbon intensity figures depend on the assumed lifetime of the facility, and that if it operated for 35 years instead of 25, the figures would fall to 14.1 and 15.3g CO_2eq/kWh.

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