MAES MAWR SOLAR FARM

Environmental Statement: Appendix 8.3 – GHG Calculations

NP12442
V1
April 2022

Document status

Version	Purpose of document	Authored by	Reviewed by	Approved by	Review date
0	First draft	Stephen Turtle	-	-	-
1	Internal review	Stephen Turtle	Tom Dearing	-	07/04/22
2	Draft for client review	Stephen Turtle	-	Tom Dearing	-

Approval for issue

Tom Dearing	7 April 2022

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1 GHG CALCULATIONS

1.1 This appendix includes further technical detail regarding the methodology and calculations outlined within Chapter 8: Climate Change. For ease of understanding, the headings used within this appendix follow those used within the main EIA chapter.

Baseline Environment

Future Baseline Conditions

1.2 The future baseline for electricity generation that would be displaced by the Proposed Development depends broadly on future energy and climate policy in the UK, and more specifically (with regard to day-to-day emissions) on the demand for operation of the Proposed Development compared to other generation sources available, influenced by commercial factors and National Grid's needs.

1.3 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.

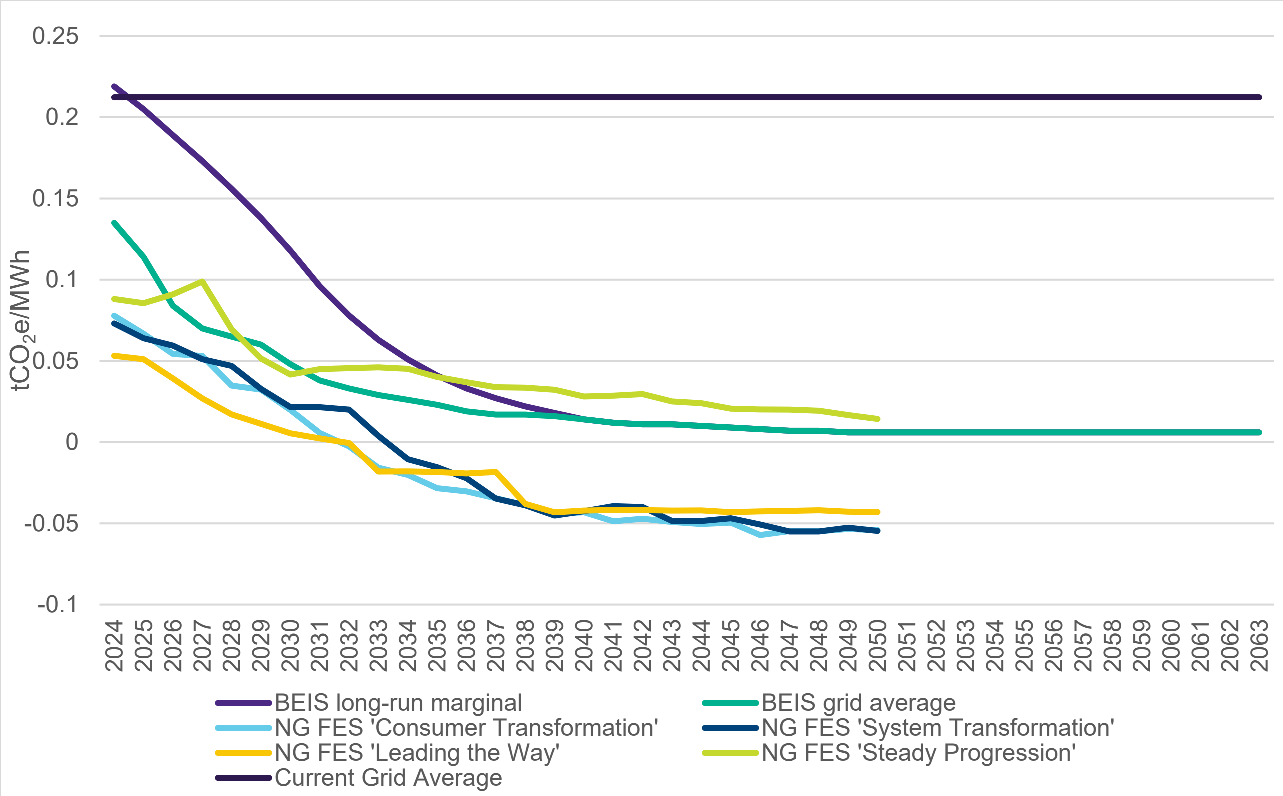
1.4 BEIS publishes projections of the carbon intensity of long-run marginal electricity generation and supply that would be affected by small (on a national scale) sustained changes in generation or demand (BEIS, 2021a). BEIS's projections over the Proposed Development's operating lifetime (2025 to 2064) are based on an interpolation from 2010's assumed marginal generator (a combined cycle gas turbine (CCGT) power station) to a modelled energy mix in 2030 consistent with energy and climate policy and predicted demand reduction scenarios by that point. 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 National Grid publishes 'Future Energy Scenario' (FES) projections (National Grid, 2021) of grid-average carbon intensity under several possible evolutions of the UK energy market, which have also been reviewed. The BEIS grid-average projection sits broadly in the middle of 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.

1.6 Graph 1 illustrates both the BEIS and National Grid projected carbon intensity factors for displaced electricity generation.

1.7 As can be seen from Graph 1, some of the FES grid-average carbon intensity projections achieve net negative values due to the sequestration of biogenic CO_2, via biomass facilities fitted with carbon capture utilisation and storage (CCUS). It has been assumed that the Proposed Development would not displace other forms of electricity generation with net negative GHG effects.

Graph 1: Grid Carbon Intensities



Assessment of Construction Effects

Assessment of Effects on Climate Change

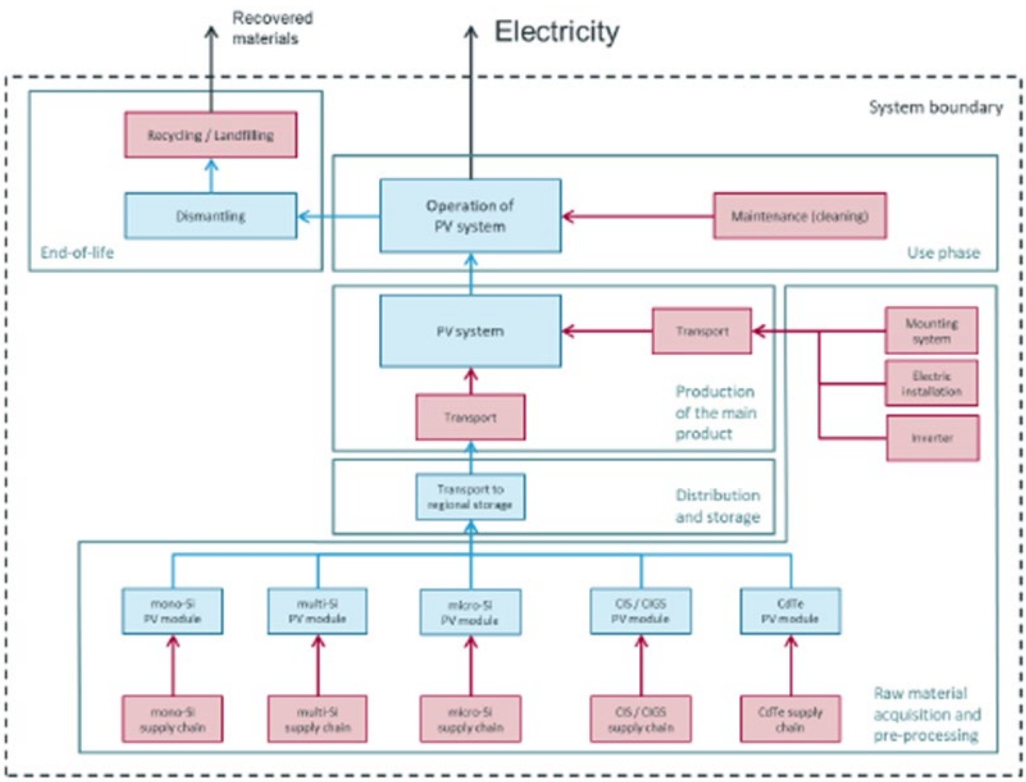
Magnitude of Impact

1.8 The installation of a 30 MW solar PV array would result in both direct and indirect greenhouse gas (GHG) emissions at all stages of the Proposed Development's lifecycle. These emissions would occur as a result of the extraction of necessary raw materials, manufacturing of the panels and associated balance of system (BoS)[1], transportation of materials to the site, the onsite assembly/construction of the PV array, ongoing maintenance and end of life (EoL) treatment.

1.9 The quantification of the emissions resulting from these activities requires a GHG Lifecycle Assessment (LCA). Figure 1 below displays the system boundaries considered in a typical GHG LCA for a PV development of this nature.

[1] BoS components are predominantly comprised of inverters, electrical cabling and frames/mounting structures.

Figure 1: System boundaries for a solar PV development (IEA, 2020)



1.10 Currently, 95% of total global PV production is accounted for by crystalline silicon (c-Si) panel technology (66% of which is accounted for by mono-crystaline (mono c-Si) and 34% by multi-crystalline (multi c-Si)) (ISE, 2020). Furthermore, the options which are currently being considered as the chosen design are either mono c-Si or multi c-Si panels. As such, only these two technology types have been considered in the assessment of GHG effects.

1.11 Emerging technologies for high efficiency c-Si panel types such as passivated emitter and rear contact (PERC), heterojunction (HJT), and interdigitated back contact (IBC) technology are becoming more readily available on the market, however, robust LCA information for such technology types is not yet available. This assessment has therefore concentrated on established first generation c-Si panel technologies.

1.12 The key GHG emitting process involved in the manufacturing of c-Si panels and associated BoS components are as follows.

- The extraction of quartz, from which metallurgical-grade silicon is extracted. This silicon is then further purified into solar-grade silicon, typically via the energy intensive Siemens reactor method.
- The forming of silicon ingots: an electricity-intensive process requiring 32 kWh per kg of mono-Si ingot (via the Czochralski process), or 7 kWh per kg of multi-Si ingot (IEA, 2020).
- The extraction of raw materials for and manufacturing of BoS components, e.g. silica for glass, copper ore for cables, iron and zinc ore extraction and refinement for mounting structures and bauxite extraction and refinement for module framing (c-Si modules require circa 2.1 kg of aluminium per m^2 of module) (IEA, 2015).

1.13 The emissions resulting from the processes described above, as well as the emissions occurring due to the transportation of materials to site and onsite emissions occurring during the assembly of the Proposed Development account for circa 70% of total lifecycle GHG emissions (not including the avoided emissions resulting from the displacement of more carbon intensive electricity generation) (NREL, 2012)

1.14 Solar PV LCAs are a complex process, given the large number of materials and processes involved in the production of PV modules and BoS components. Furthermore, the associated GHG emissions are dependent on the location (and associated energy mix) of where these processes are occurring. As such – and in the absence of greater detail regarding panel types and manufacturer specifications etc – a detailed LCA is beyond the scope of this assessment. Instead, a robust approach has been formulated by considering meta analyses of published solar PV LCAs, thereby accounting for the likely range of magnitude of the Proposed Development's construction-stage GHG emissions. Further detail is given in the next section.

Emissions factors and data sources

1.15 The current literature surrounding PV system LCAs is characterised by a high degree of variability in its published GHG figures, and therefore a degree of uncertainty occurs in selecting any one of these figures as a means of analysing the embodied GHGs in constructing a solar array. As a means of dealing with this uncertainty, the primary source of emissions factors used in assessing the embodied carbon effects of the Proposed Development was NREL's (2012) 'Life Cycle Greenhouse Gas Emissions of Crystalline Silicon Photovoltaic Electricity Generation'. The study constituted a meta-analysis of over 397 LCAs regarding C-SI PV systems, all of which were subject to a screening process, and for those which passed the screening process, a subsequent harmonisation process. Using the NREL study as a means of acquiring GHG factors for construction-stage[2] GHG emissions partially eliminated the large degree of variability and uncertainty in the published literature surrounding PV LCAs, and ensured the range of construction-stage GHG emissions stated in this chapter represent the most realistic and accurate effects.

1.16 The screening process removed the majority of the considered studies, so that the meta-analyses considered in detail only 13 studies (containing a total of 42 Lifecycle GHG factors). The screening process ensured that minimum standards for the following criteria were met:

- Quality: the study used an accepted LCA methodology (e.g. ISO 14040 (ISO, 2006));
- Transparency: the study described its methods, sources and values of input data; and
- Relevance: relevant, up-to-date technology was analysed.

1.17 As well as the lifecycle GHG implications of PV systems being sensitive to the energy input/mix required for their manufacturing and production, they are also sensitive to other input parameters including module efficiency, solar insolation, system lifetime and performance ratio[3] (Pacca et al, 2007). As a means of accounting for potential variability due to these factors, the LCA studies in NREL's meta study were subject to a harmonisation process. The process involved correcting the considered LCA results following the normalisation of the aforementioned input parameters. Table 1.1 states the input parameters used in the harmonisation process and subsequent generation of improved lifecycle GHG factors for PV systems.

[2] Construction-stage – in this sense – also refers to the emissions associated with maintenance and any EoL treatment-related emissions. It excluded the GHG implication of exporting low carbon power onto the grid.

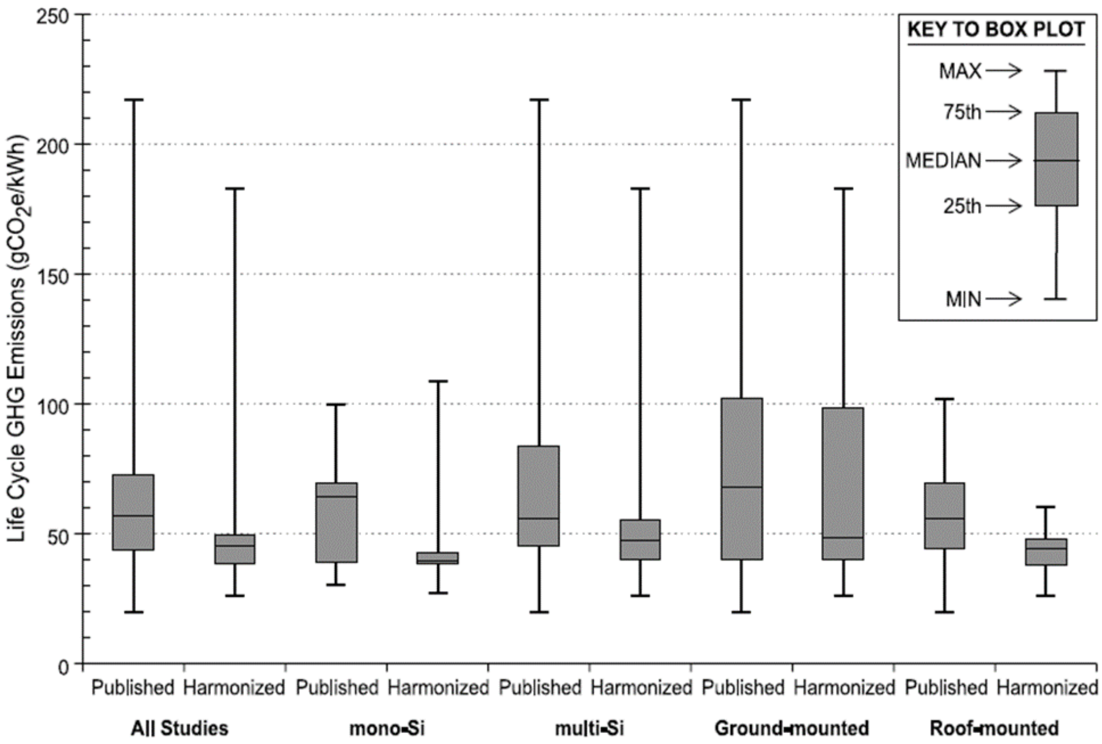
[3] Performance ratio refers to the difference in potential energy output (for a given module efficiency and annual solar insolation value), and actual energy output. The performance ratio is determined by BoS efficiency losses (namely inverter and cabling losses), cell mismatch, elevated PV module temperature, reflection from the module front surface, soiling, shading, and component failures.

Table 1.1: NREL harmonised input parameters

Solar insolation (kWh/m²/yr)	System lifetime (years)	c-Si module efficiency (%)		Performance ratio	
		Mono	Multi	Ground-Mounted	Rooftop
1,700	30	14	13.2	0.8	0.75

1.18 Based on the input parameters in Table 1.1, the NREL study generated a range of harmonised GHG impacts. These are displayed in Figure 2.

Figure 2: NREL lifecycle GHG emissions factors (NREL, 2012)



1.19 Based on Figure 2, it was decided that the range of emissions factors that would most closely represent the possible range of construction-stage GHG emissions for both possible technology types for the Proposed Development would be the lower quartile range (LQR) and upper quartile range (UQR) values for all LCAs considered in the meta-analysis. These have represented the upper and lower limits of the range presented in this assessment. Therefore, the initial range of values being considered were 39 to 49 gCO_2e/kWh (with a median value of 44 gCO_2e/kWh).

1.20 The lifetime GHG emissions factor – when expressed in terms of the system's lifetime energy output (i.e in terms of kWh) – is sensitive to the annual insolation value used in the calculation. The harmonized insolation value of 1,700 $kWh/m^2/yr$ used in the NREL study is representative of the meteorological conditions of southern Europe.

1.21 The IEA's (2020) 'Life Cycle Inventories and Life Cycle Assessments of Photovoltaic Systems' report contains country specific annual average solar energy yields, whereby average annual energy outputs from PV systems in various countries are expressed in terms of the peak capacity of the system. An average annual energy yield (in terms of annual kWh/kW_p[4]) for a solar array in southern Europe was obtained by averaging the same values for Spain, Portugal, Italy and Greece. This value

[4] 'W_p' refers to the nominal power of a solar array, i.e. its peak generation capacity.

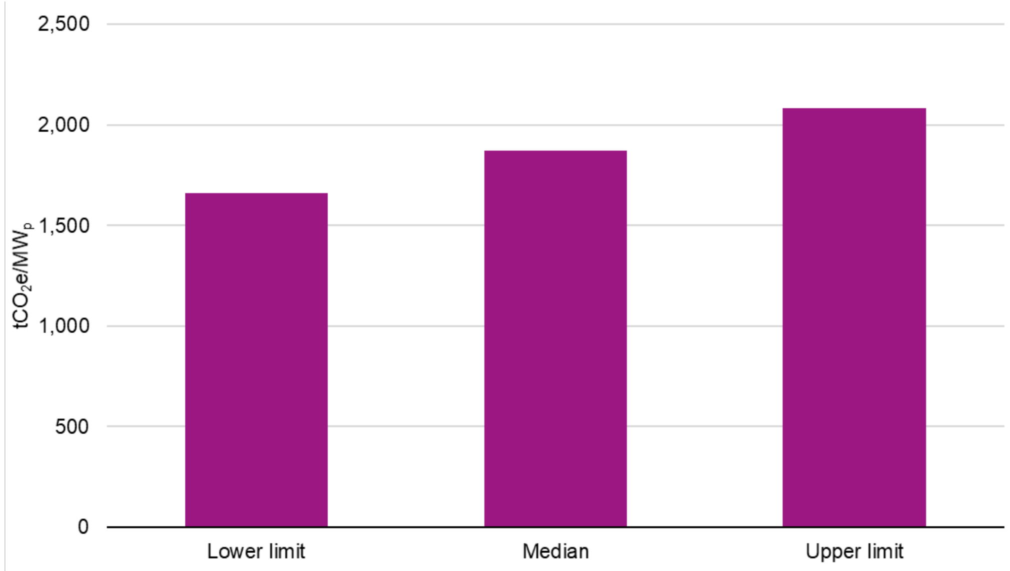
was then used to factor out the annual energy output for the lifetime GHG emissions factor, so that the emissions factor could be expressed in terms of gCO_2e/MW (i.e. in terms of installed capacity rather than lifetime energy generation), and therefore representative of the likely range of construction-stage GHG effects of the UK-based Proposed Development. The lifetime GHG factors, expressed as gCO_2e/MW could then be multiplied by the 80 MW generating capacity of the Proposed Development in order to calculate the construction-stage GHG impacts in tCO_2e.

1.22 Table 1.2 and Graph 2 display these construction-stage GHG intensities and impacts of the Proposed Development, as well as the possible upper and lower limits.

Table 1.2: Construction stage GHG emissions factors and impacts

	Lower limit	Median	Upper limit
Lifecycle GHG intensity (gCO_2e/kWh)	39	44	49
Average annual energy yield[5] (kWh/kW_p)	1,419	1,419	1,419
Operating lifetime (yrs)	30	30	30
Total GHG (gCO_2e/kW_p)	1,659,645	1,872,420	2,085,195
Total GHG (tCO_2e/MW_p)	1,660	1,872	2,085
Total Development GHG (tCO_2e)	**49,789**	**56,173**	**62,556**

Graph 2: Total construction stage GHG impacts



1.23 A potential limitation of this assessment is the age of the meta-analysis study that has used to inform the potential construction-stage GHG emissions. So as to provide further confidence in the results expressed in Table 1.2, a recent study by Milouisi et al (2019) was also considered. This study calculated the lifecycle GHG implications of 3 kW PV systems of varying panel technology in Crete, which were therefore under similar irradiance conditions to the harmonized irradiance value expressed in the NREL study. The Milousi et al (2019) study concluded that mono-Si systems have a lifecycle GHG impact of 52.4 gCO_2e/kWh, whilst multi-Si systems have a lifecycle GHG impact of

[5] For a solar array in southern Europe

44.3 gCO_2e/kWh. These results provide further confidence that the results expressed in Table 1.2 are in the correct order of magnitude.

Assessment of Operational Effects

Assessment of Effects on Climate Change

Magnitude of Impact

1.24 The 30 MW solar array would export energy to the grid that is zero-carbon at the point of generation[6], thereby displacing the marginal generating source that would be providing energy in the absence of the Proposed Development.

1.25 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, the current grid average figure of 0.21233 $kgCO_2e/kWh$ (BEIS, 2022) has been used as the baseline for this assessment as projected grid decarbonisation scenarios rely on the implementation of renewable energy generation that is provided by projects such as the proposed development.

1.26 The carbon intensity of the marginal generating source has been discussed in the future baseline conditions section.

1.27 The annual energy output of the Proposed Development has been calculated assuming a load factor of 9.91%, as calculated from Government Feed-in-Tariff data for solar PV installations in Wales from 2011/12 to 2020/21 (BEIS, 2021b). The annual load factor of solar PV facility refers to the total number of hours at which the facility is generating electricity at its rated capacity (i.e. 30 MW for the Proposed Development), over the total number of hours in a year. A PV facility's load factor is determined by irradiance conditions, performance ratio and orientation and tilt of the panels. The FiT data will include both domestic and commercial systems up to 5 MW in scale, and is likely to be conservative for the performance of a utility-scale array that can be better optimised in its installation than domestic systems in particular.

1.28 The energy output calculation has also taken into consideration the degradation factor of the PV modules, assumed to be 0.7% per annum (IEA, 2021).

1.29 Table 1.3 display the expected annual energy generation and operational GHG effects for the Proposed Development, based on the current grid average figure of 0.21233 $kgCO_2e/kWh$ (BEIS, 2022). Over the Proposed Development's 40 year lifetime it has been calculated to output 911,183 MWh, resulting in 193,472 tCO_2e avoided emissions.

Table 1.3: Expected annual energy generation and operational GHG effects

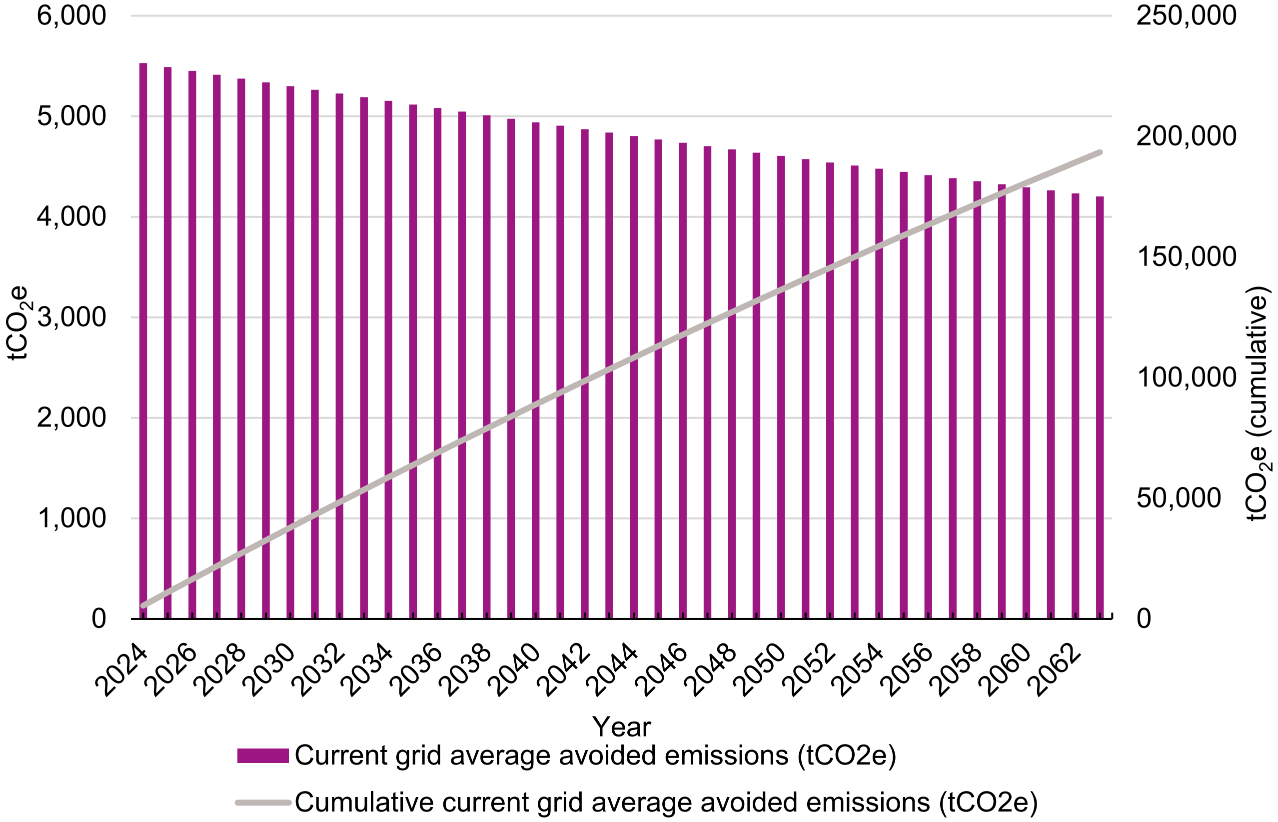
Year of Operation	Year	Output (MWh)	Current grid average avoided emissions (tCO_2e)	Cumulative current grid average avoided emissions (tCO_2e)
1	2024	26,038	5,529	5,529
2	2025	25,856	5,490	11,019
3	2026	25,675	5,452	16,470
4	2027	25,495	5,413	21,884
5	2028	25,317	5,375	27,259
6	2029	25,139	5,338	32,597

[6] i.e not including the embodied carbon emissions associated with the construction of the array discussed in the construction effects section.

7	2030	24,963	5,300	37,897
8	2031	24,789	5,263	43,161
9	2032	24,615	5,227	48,387
10	2033	24,443	5,190	53,577
11	2034	24,272	5,154	58,731
12	2035	24,102	5,118	63,848
13	2036	23,933	5,082	68,930
14	2037	23,766	5,046	73,976
15	2038	23,599	5,011	78,987
16	2039	23,434	4,976	83,963
17	2040	23,270	4,941	88,904
18	2041	23,107	4,906	93,810
19	2042	22,945	4,872	98,682
20	2043	22,785	4,838	103,520
21	2044	22,625	4,804	108,324
22	2045	22,467	4,770	113,094
23	2046	22,310	4,737	117,831
24	2047	22,153	4,704	122,535
25	2048	21,998	4,671	127,206
26	2049	21,844	4,638	131,844
27	2050	21,691	4,606	136,450
28	2051	21,540	4,574	141,024
29	2052	21,389	4,541	145,565
30	2053	21,239	4,510	150,075
31	2054	21,090	4,478	154,553
32	2055	20,943	4,447	159,000
33	2056	20,796	4,416	163,415
34	2057	20,651	4,385	167,800
35	2058	20,506	4,354	172,154
36	2059	20,363	4,324	176,478
37	2060	20,220	4,293	180,771
38	2061	20,078	4,263	185,034
39	2062	19,938	4,233	189,268
40	2063	19,798	4,204	193,472

1.30 Graph 3 offers a visual representation of Table 1.3, displaying the anticipated annual avoided emissions, and cumulative avoided emissions over the Proposed Development's lifetime.

Graph 3: Annual and Cumulative GHG impacts



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