Botley West Solar Farm

Environmental Statement

Volume 3

Appendix 14.2: Greenhouse Gas Calculations

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Contents

Tables

Graphs

14 Climate Change Greenhouse Gas Calculations

14.1 Introduction

14.1.1 This appendix includes further technical detail regarding the methodology and calculations outlined within Volume 1 Chapter 14: Climate change of the Environmental Statement (ES) **[EN010147/APP/6.3]**.

14.2 Scope

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

14.2.2 The appendix scope considers the emissions associated with the construction, operation and maintenance, and decommissioning phases of the Project. Key emissions sources relevant in the assessment are:

- land use change within the project boundary;
- embodied carbon emissions in materials;
- transport emissions; and
- avoided emissions associated with the abatement of required fossil fuel generators and their associated emissions related with the UK electricity grid.

14.3 Methodology

Overview

14.3.1 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 Project have been informed via the following source:

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

14.3.2 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.

14.3.3 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 Project. These emissions shall not be separated out by defined scopes (Scopes 1, 2 or 3) in the assessment.

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

14.3.5 Emissions resulting from the manufacturing and construction of the solar panels, Balance of Systems (BoS) infrastructure, alongside other elements of the Project have been calculated via a mix of published benchmark carbon intensities, and lifecycle analysis (LCA) Environmental Product Declarations (EPD's). EPD's have either been identified by the applicant as a preferred component option at time of the ES, or extracted from OneClick LCA[1]. Key sources relied upon for the assessment are as follows:

- One Click LCA Software (OneClick LCA, 2024)
- Longi LR5 72HGD 590w PV module EPD (EPD-Norway, 2024)
- Hot dip galvanized steel with Magnelis® coating EPD (IBU-EPD, 2019)
- SMA Solar Central Power Inverter – Sunny Central 4600 UP LCA (Fraunhofer IBP, 2024).
- Inventory of Carbon and Energy (ICE) Database V3.0 (ICE, 2019)

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

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

[1] OneClick LCA is a life-cycle assessment software containing a large database of building material characteristics and embodied carbon intensities, based on published environmental product declarations (EPDs) and known carbon intensities for generic construction materials.

Embodied Carbon

14.3.8 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 a solar farm, encompassing either a cradle-to-gate (Project site) or a cradle-to-grave (accounting for in use and decommissioning) approach. This can be further broken down into the following LCA phases of development:

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

14.3.9 Additional to GHG emissions associated with life cycle stages A1 – C4 are D stage GHG emissions. D stage falls beyond the product life cycle and encompasses benefits and loads beyond the system boundary. This includes reuse, recovery, or any recycling potential of materials which may reduce the overall embodied carbon footprint of a material once this stage is accounted for. Emissions associated with D stage emissions have been accounted for within the decommissioning section (section 14.7) as the relevant commitment to end of life treatment of the products and materials is within the Outline Decommissioning Plan **[EN010147/APP/7.6.4]**.

14.3.10 For reference, a diagram setting out the various life-cycle stages of a whole life carbon assessment is set out below in Figure 14.1.

Figure 14.1: GHG Emissions life-cycle stages

Whole Life Carbon Assessment: Life-cycle modules (BS EN 15978)														
Development Life-cycle Information														Supplementary Information Beyond the Development Life-cycle
A1 - A3			A4 - A5		B1 - B7					C1 - C4				D
Product stage			Construction process stage		Use stage					End-of-Life stage				Benefits and loads beyond the system boundary
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4	
Raw material extraction and supply	Transport to manufacturing plant	Manufacturing & fabrication	Transport to project site	Construction & installation process	Use	Maintenance	Repair	Replacement	Refurbishment	Deconstruction & demolition	Transport to disposal facility	Waste processing for reuse, recovery or recycling	Disposal	Reuse Recovery Recycling potential
					B6: Operational energy use									
					B7: Operational water use									

14.3.11 At PEIR stage, the Project was in its early stages of design, as such, data relating to specific metrics for site specific design details including chosen manufacturer of Solar PV panels etc. was unavailable. Therefore, data was extracted from peer reviewed reports and UK Government bodies to provide estimate baseline figures for each stage of the LCA. Since then, Indicative design details for the Project have been identified by the applicant, and a preferred PV panel manufacturer and model has been selected (with EPD utilised for the purposes of this assessment).

Land Use Change

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

Operational Avoided Emissions

14.3.13 The assessment also considers the GHG emissions that would not be generated (i.e. avoided) during the operation of the Project during the future baseline (see Future Baseline Conditions section below).

14.4 Baseline Environment

Current Baseline

14.4.1 With regard to GHG emissions, the current baseline is agricultural land, comprised of a series of agricultural fields of varying sizes. They are primarily used for pasture grazing and arable farming. This land is unlikely to have high soil or vegetation carbon stocks (e.g. peat and woodland) that would be subject to disturbance by construction.

14.4.2 With regard to the electricity export of the Project, the baseline is the current average grid electricity carbon intensity. This value has been taken from published benchmarks (DESNZ, 2024) and is 0.25692 kgCO_2e/kWh, which is inclusive of Well-to-tank (WTT) and WTT Transmission and Distribution (T&D) Losses.

Future Baseline Conditions

14.4.3 The future baseline for electricity generation that would be displaced by the Project 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 Project compared to other generation sources available, influenced by commercial factors and National Grid's needs.

14.4.4 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.

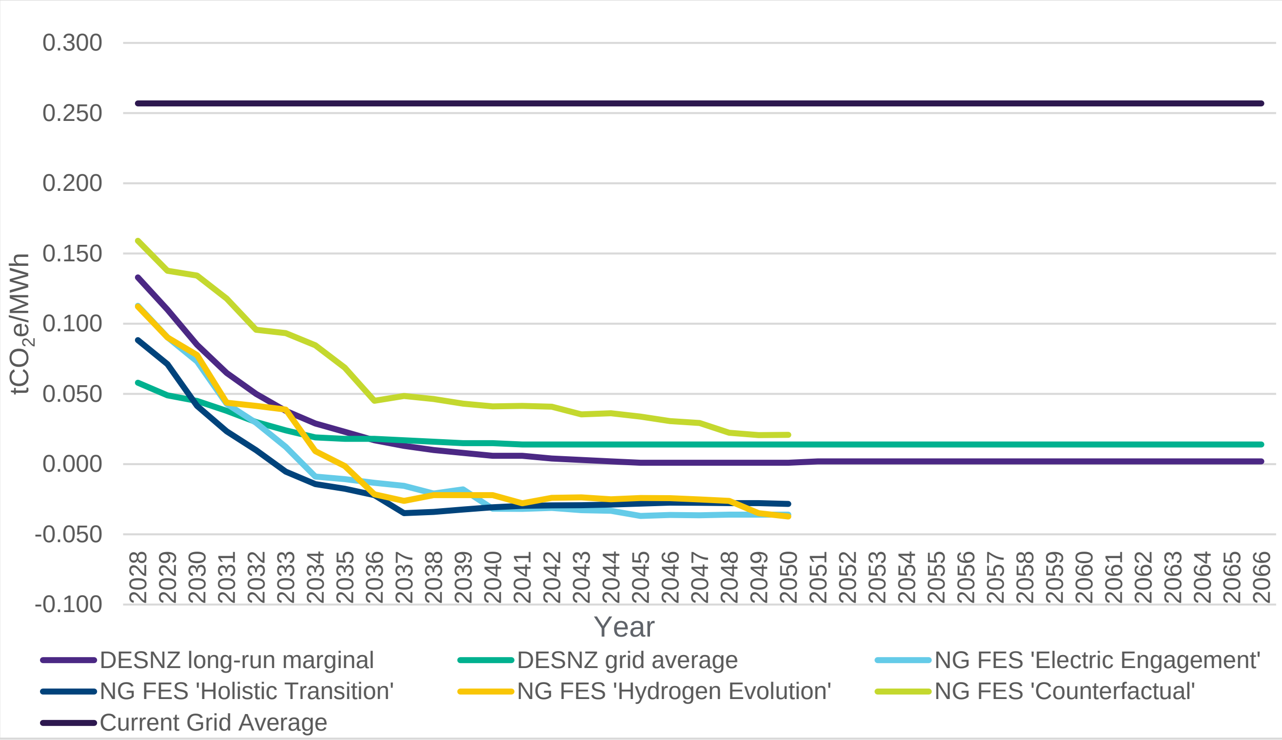
14.4.5 The UK government Department for Energy Security and Net Zero (DESNZ) (Formerly released under the government department for Business, Energy and Industrial Strategy (BEIS)) have published projections of the carbon intensity of long-run marginal electricity generation and supply that would be affected by small (on a national scale) sustained changes in generation or demand (DESNZ, 2023). DESNZ's projections over the Project's operating lifetime (2028 to 2066) 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 DESNZ for 2040 and the marginal factor is assumed to converge with it by that date, interpolated between 2030 and 2040; both factors are then further interpolated from 2040 to a national goal for carbon intensity of electricity generation in 2050 and assumed to be constant after that point.

14.4.6 National Grid publishes 'Future Energy Scenario' (FES) projections (National Grid, 2024) of grid-average carbon intensity under several possible evolutions of the UK energy market, which have also been reviewed. The DESNZ grid-average projection sits broadly in the middle of the National Grid range, and as stated above, the marginal factor is assumed by DESNZ to converge with it (and hence with National Grid's scenarios) over time.

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

14.4.8 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 carbon dioxide (CO_2), via biomass facilities fitted with carbon capture utilisation and storage (CCUS). It has been assumed that the Project would not displace other forms of electricity generation with net negative GHG effects.

Graph 1: Grid Carbon Intensities



14.5 Assessment of Construction Effects on Climate Change

Land Use Change

The majority of the development site area is identified as likely to be Grade 3 agricultural land and further surveys have been undertaken to ascertain whether it is considered 'best and most versatile' (BMV) agricultural land. It is unlikely that any of the site area would be considered to have significant levels of carbon content in soils.

The majority of the site is used for arable farming and as such is unlikely to have any significant long term carbon storage value. As such the change concerning the carbon storage value of the land use would be minimal if not slightly beneficial in the long term with the change to grassland throughout the life time of the Project.

Embodied Carbon

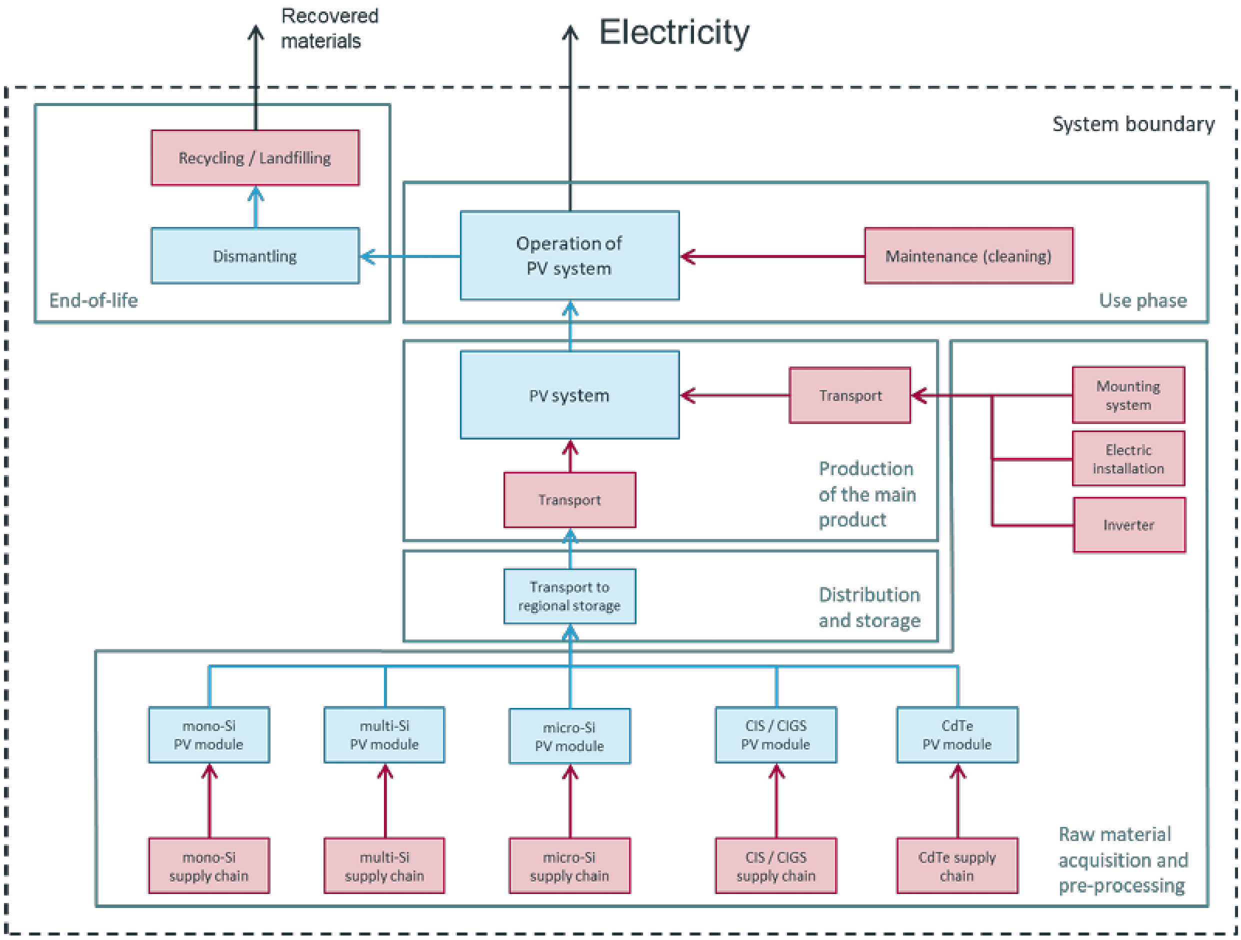
14.5.1 The installation of an 840 MW solar PV array would result in both direct and indirect greenhouse gas emissions at all stages of the Project's lifecycle. These emissions would occur as a result of the extraction of necessary raw materials, manufacturing of the panels and associated balance of system (BoS)[2] components, transportation of materials to the site, the onsite

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

assembly/construction of the PV array, ongoing maintenance and end of life (EoL) treatment.

14.5.2 The quantification of the emissions resulting from these activities requires a GHG Lifecycle Assessment (LCA). Figure 14.2 below displays the system boundaries considered in a typical GHG LCA for a PV development of this nature.

Figure 14.2: System Boundaries for a Solar PV Development (IEA, 2020) Future Baseline Conditions



14.5.3 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-crystalline (mono c-Si) and 34% by multi-crystalline (multi c-Si)) (ISE, 2020). The specific panel type for the Project has been selected (Mono c-Si panel), and a preferred supplier has been identified. The assessment of GHG effects utilises an Environmental Product Declaration (EPD) from the preferred supplier, for the preferred module type, to conduct the PV module LCA, thus increasing the accuracy of assessment.

14.5.4 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).

14.5.5 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 Project account for the majority of total lifecycle GHG emissions (not including the avoided emissions resulting from the displacement of more carbon intensive electricity generation) (NREL, 2012).

14.5.6 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. For the purposes of quantifying the GHG emissions associated with the Project during construction, the following elements of the Project have been assessed as part of this LCA:

- PV Modules
- PV Module Frames (piles and mounting structure)
- Inverters
- Cabling – Direct Current (DC) 6 mm
- Cabling - DC 150 mm
- Cabling – Alternating Current (AC) 33 kv
- Cabling - AC 275 kv
- Cabling - Fibre Optic
- Project Substations
- National Grid Electricity Transmission (NGET) Substation[3]
- Power Converter Stations (PCS)
- Deer Proof Fencing
- Security Fencing
- Gates (regular + security)

14.5.7 Further detail is given in the next section.

[3] It should be noted that whilst the NGET substation is being assessed as part of the application, it is being brought forward and delivered by NGET. As such, the client has no control over design decisions of this component and is accounting for estimated emissions as part of the assessment.

Emissions Factors and Data Sources

14.5.8 Emissions Factors and data sources for the various components associated with the construction of the Project are detailed below. It should be noted that all components listed have accounted for A1-A3 life cycle stages, whereas the A4 (transportation to site), and A5 (site) life cycle stage emissions, have been accounted for within the Construction Transport Emissions (A4) and Site Emissions (A5) sections.

PV Modules

14.5.9 Emissions arising from the construction of PV modules for the Project have been derived from an EPD for the nominated preferred module provided by the applicant, a Longi LR5 72HGD 590w PV module (EPD-Norway,2024).

14.5.10 The EPD which has been relied upon for the PV modules (EPD-Norway,2024), states an emissions factor of 0.368 kgCO_2e/Wp for A1-A3 life-cycle stage emissions. To be conservative and estimate emissions associated with a maximum design scenario this has been scaled by the maximum generation capacity of the Project (1,375 MWp), resulting in 506,000 tCO_2e.

PV Module Frames (Piles and Mounting Structure)

14.5.11 The EPD for PV module frames (IBU-EPD,2019) is for hot-dipped galvanised steel with a magnelis coating (a zinc-aluminium-magnesium alloy). It states a GHG emissions factor for the construction stage (A1-A3) of 2.57 tCO_2e/tonne of material. When scaled by the total estimated weight of material required for PV module frames (38,183 tonnes, Volume 3, Appendix 12.6: Construction Vehicle Trip Generation Assumptions (Annex A) **[EN010147/APP/6.5]**), this amounts to 98,131 tCO_2e.

Inverters

14.5.12 Inverters associated with the Project will be stored within the PCS units, with each PCS housing two inverters. Remaining PCS unit components (Housing, Transformers, Concrete for foundations), are assessed within the section below.

14.5.13 The EPD for inverters (Fraunhofer IBP, 2024) utilised for this assessment is for a SMA Solar, Sunny Central 4600 UP power inverter. It states an emissions factor of 14,836 kgCO_2e per inverter, related to A1-A3 life-cycle stage emissions. Once scaled by the required number of inverters for the construction of the Project (312), this amounts to 4,629 tCO_2e.

Substations and Power Converter Stations (PCS)

14.5.14 The impact of the proposed substations and PCS' has been estimated using an intensity for the manufacturing GWP of 2,190 kgCO_2e per MVA (ABB, 2003). This was scaled by the total capacity of transformers utilised in the construction of substations and PCS' from the Project Description, 4,316 MVA. This gives an estimated embodied carbon value of 9,452 tCO_2e.

- PCS: 156 MV transformers (6 MVA each) – 936 MVA.
- Secondary Substations (x6): Combined maximum power rating – 1,000 MVA.
- Main substation: 2 x 500 MVA HV transformers – 1,000 MVA.
- NGET Substation: 3 x 460 MVA transformers – 1,380 MVA.

14.5.15 The various substations and PCS elements are to be housed within a number of main buildings. At this stage of design, material estimates have some uncertainty in terms of their quantities and specific products to be used in the final, detailed design. As such, a published benchmark (RICS, 2012) has therefore also been used to estimate possible emissions from the substation and PCS buildings. A carbon intensity of 545 $kgCO_2e/m^2$ was scaled by the total maximum area of proposed buildings, totalling 54,094 m^2, to give an embodied carbon value of 29,481 tCO_2e.

14.5.16 An estimated total weight of concrete associated with Project substations (not including NGET substation) and PCS foundations' has been provided (1,782t). This has been quantified by applying an emissions factor of 0.1382 tCO_2e/t for 32/40 MPA concrete from the ICE Database (ICE, 2019), resulting in an additional 246.3 tCO_2e.

14.5.17 A breakdown of building footprints within the 54,094 m^2 total are as follows:

- NGET substation: 38,000 m^2
- Main substation: 8,680 mf^2
- Secondary substations: 6 x 180 m^2 – 1,080 m^2
- PCS: 156 x 40.6 m^2 – 6,334 m^2

14.5.18 Therefore, when combining GHG emissions from transformers with substation and PCS housing, and concrete foundations, construction emissions for this element of the Project amounts to 39,180 tCO_2e.

Cabling

14.5.19 Total weights of cables can be found in Volume 3, Appendix 12.6: Construction Vehicle Trip Generation Assumptions (Annex A) **[EN010147/APP/6.5]**, including indicative material breakdown within cables. This information is laid out below in Table 14.1.

14.5.20 Cables are made up predominantly of copper and insulation, as such, weights of each of these materials within cables has been provided and assessed. Additional miscellaneous materials are considered immaterial and have not been assessed.

Table 14.1: Project Cable Weights and associated GHG emissions

Cable	Weight (tonnes)			GHG emissions (tCO_2e)		
	Total	Copper	Insulation	Copper	Insulation	Total
DC Cabling (6 mm^2)	1,284	847	415	2,295	1,054	**3,349**
DC Cabling (150 mm^2)	2,320	2,000	304	5,420	772	**6,192**
AC Cabling (33 kv)	811	433	359	1,173	912	**2,085**
AC Cabling (275 kv)	2,059	1,010	997	2,737	2,532	**5,269**

14.5.21 Emissions factors applied to copper and insulation weights within cables are as follows:

- Copper – 2.71 tCO_2e/t (ICE, 2019)
- Insulation – 'General Polyethylene' 2.54 tCO_2e/t (OneClick, 2024)

14.5.22 In addition to the cables listed in Table 14.1, the Project entails 9 tonnes of fibre optic cabling. Of which, GHG emissions have been quantified utilising information available on OneClick LCA. From OneClick, an EPD for a fibre optic cable (EPD Number: CAEG-00001-V01.01-FR, 33799 – INIES) stated the density of a fibre optic cable to be 0.047 kg/m. The 9 t of fibre optic cable has been converted into this metric and scaled by an emissions factor of 0.19 $kgCO_2e/m$, resulting in 36.4 tCO_2e.

14.5.23 In addition to the cables mentioned above, a total weight (3,181 tonnes) has also been provided for stainless steel utilised for strip grounding (for earthing purposes). The total weight of stainless-steel strip grounding was applied to the ICE database (2019) emissions factor for galvanised steel of 2.76 $kgCO_2e/kg$ (A1-A3 stage), resulting in an additional 8,780 tCO_2e to the construction stage of the project.

14.5.24 In total, emissions associated with the cabling and strip grounding elements of the Project amounts to 25,713 tCO_2e.

Fencing and Gates

14.5.25 GHG emissions from a range of fences and gates included in the Project design have been quantified, broken down into the following:

- Deer proof fencing – 105,578 m
- Steel security fencing (around substations) – 1,500 m
- Regular steel gates – no.160
- Steel security gates – no. 7

14.5.26 In relation to the deer proof fencing that will be present across the Project site, an internally verified EPD from the OneClick LCA software has been utilised, entitled 'wildlife fence, galvanized steel mesh, wooden posts', of which the stated emissions factor is 4.3 $kgCO_2e/m$. Once scaled by the total length of deer proof fencing required for the Project, this results in an additional 454 tCO_2e.

14.5.27 It has been assumed that the remaining elements of this section (steel security fencing, regular steel gates, and steel security gates), are constructed predominately from steel and any other material would be insignificant in the assessment of GHG emissions. As such, an emissions factor of 2.76 tCO_2e/t has been applied to them from the ICE database (2019), for 'Hot-dip galvanised steel'.

14.5.28 Using weight estimations provided of 200 kg per regular steel gate, and 400 kg per steel security gate, and 14.3 kg per 3 metres of steel security fencing, a total weight of steel required for the construction of these elements of the Project was estimated to be 32 t for regular gates, and 2.8 t for security gates, and 7.1 t for security fencing, totalling to 41.9 t of steel. This information is provided in Volume 3, Appendix 12.6: Construction Vehicle Trip Generation Assumptions (Annex A) **[EN010147/APP/6.5].**

14.5.29 The total weight of steel for these elements was then applied to the emissions factor above in 14.5.27, resulting in the following GHG emissions:

- Steel security fencing – 20 tCO_2e.
- Regular steel gates – 88 tCO_2e.
- Steel security gates – 8 tCO_2e.

14.5.30 In total, GHG construction emissions associated with the various fencing and gates for the Project amounts to 570 tCO_2e.

Construction Transport Emissions (A4)

14.5.31 As detailed above, the estimation of embodied carbon from project materials accounts for A1-A3 life-cycle stage basis for the assessment of construction effects.

14.5.32 To account for the A4 stage emissions during construction of the Project, the following transport movements have been quantified:

- HGV movements;
- construction staff movements (minibuses);
- on site Supervisor / controller activity (4x4) movements; and
- international shipping (cargo ship).

HGV Movements

14.5.33 Estimated total HGV movements during construction totals 25,709 HGV journeys during the construction period (Volume 3, Appendix 12.6: Construction Vehicle Trip Generation Assumptions (Annex A) **[EN010147/APP/6.5]**).

14.5.34 To provide a conservative, worst case estimate, it is assumed that all truck movements are return journeys from the Project site to the Dover ferry port (240 km), resulting in a distance of 480 km per required HGV journey.

14.5.35 An emissions factor of 0.87296 kgCO_2e/km for 'average laden (All HGV's)' (DESNZ, 2024) has been scaled by 480 km, resulting in 0.419 tCO_2e per estimated HGV movement.

14.5.36 Once total estimated HGV movements for the construction stage of the Project are considered, this results in 8,355 tCO_2e.

Construction staff movements

14.5.37 Estimated total construction staff movements during construction totals 4,400[4] journeys during the construction period ((Volume 3, Appendix 12.6: Construction Vehicle Trip Generation Assumptions (Annex A) **[EN010147/APP/6.5]**).

14.5.38 To provide a conservative, worst case estimate, it is assumed that all movements are return journeys from the Project site construction compounds, accounting for journeys around site, before returning to the Project site construction compounds. A movement around site is assumed to be covered in 10 km, resulting in 20 km per required return journey.

14.5.39 An emissions factor of 0.19757 kgCO_2e/km for 'dual purpose 4x4' (DESNZ, 2024) has been scaled by 20 km, resulting in 4 kgCO_2e per estimated return movement.

14.5.40 Once total estimated construction staff movements for the construction stage of the Project are considered, this results in 43 tCO_2e.

On site supervisor / controller activity

14.5.41 Estimated total on site supervisor / controller movements during construction totals 11,000[5] journeys during the construction period ((Volume 3, Appendix 12.6: Construction Vehicle Trip Generation Assumptions (Annex A) **[EN010147/APP/6.5]**).

14.5.42 To provide a conservative, worst case estimate, it is assumed that all movements are return journeys from the Project site to construction worker accommodation, assumed to be within 20 km, resulting in a distance of 40 km per required return journey.

14.5.43 An emissions factor of 0.17751 kgCO_2e/km for 'MPV' (DESNZ, 2024) has been scaled by 40 km, resulting in 7 kgCO_2e per estimated return movement.

14.5.44 Once total estimated construction staff movements for the construction stage of the Project are considered, this results in 31 tCO_2e.

International Shipping

14.5.45 It is expected that many of the products and materials used within the Project will be manufactured abroad and shipped to the UK for installation. GHG

[4] This is assumed to be 8 minibus arrivals per day, carrying construction workers to site, over a 22 month period. This accounts for the construction period from the point at which construction compounds are anticipated to be completed.

[5] This is assumed to be 20 4x4 arrivals per day, supervisors / controllers around site, over a 22 month period. This accounts for the construction period from the point at which construction compounds are anticipated to be completed.

emissions associated with the international shipping of these goods has therefore been accounted for in the GHG footprint. It is likely that the PV panels will be manufactured in China, where other materials such as cables may be sourced more locally (e.g. Europe). To provide a conservative assessment it has been assumed that all imported materials will originate in China.

14.5.46 An emissions factor of 0.01612 kgCO_2e/ t.km for international shipping (DESNZ, 2024) has been scaled by 16,000 km (distance from UK to China via Suez canal), and applied to the total weight of material associated with project components to gather expected emissions associated with shipping of components to the UK.

14.5.47 The maximum number of required PV modules (2,200,000) has been applied to the weight of a module provided in the EPD (EPD-Norway, 2024) of 31.8 kg, resulting in 69,960 tonnes as the estimated total weight of required PV modules for the construction of the Project.

14.5.48 Weights associated with the remainder of the project components (listed in 14.5.6) can be found in Volume 3, Appendix 12.6: Construction Vehicle Trip Generation Assumptions (Annex A) **[EN010147/APP/6.5]**, amounting to 69,960 tonnes of material. This amounts to a total estimated weight of 123,417 tonnes for Project component materials.

14.5.49 By combining the total weight of Project component materials stated above in paragraph 14.5.47 with the factors stated in 14.5.46, this results in 31,832 tCO_2e associated with shipping Project components to the UK.

Total

14.5.50 In total, 40,261 tCO_2e is anticipated as a result of transport during the construction phase of the Project.

Site Emissions (A5)

14.5.51 The total footprint of the construction compounds at each section of the Project site are as follows:

- Northern – 40,000 m^2 (200 m x 200 m)
- Central – 40,000 m^2 (100 m x 200 m) x 2
- Southern – 20,000 m^2 (100 m x 200 m)
- HDD Entrance Compounds – 27,000 m^2 (30 m x 75 m) x 12
- HDD Exit Compounds – 9,000 m^2 (30 m x 75 m) x 12

14.5.52 As detailed design of construction compounds has not been finalised at this stage, the total area (m^2) of construction compounds (136,000 m^2) has been scaled by a benchmark factor provided in OneClick LCA (2024), for construction site emissions (Average construction site impacts - Nordics (per GFA)). The emissions factor stated is 18.55 kgCO_2e/m^2. This factor accounts for construction waste, electricity usage, and fuel usage (diesel) during site construction activities. It should be noted that the factor stated is based on construction site activity in Norway, in the absence of available information for the UK context. It is anticipated that results from Norway would largely be in the same order of magnitude as the UK.

14.5.53 By applying the emissions factor stated above to the total area of construction compounds for the Project, this amounts to 2,523 tCO_2e in relation to construction site emissions (A5 stage).

Total

14.5.54 Combining GHG emissions from the construction of the solar farm and associated BoS, substations and associated infrastructure, total construction emissions for the Project is 717,006 tCO_2e.

14.6 Assessment of Operational Effects on Climate Change

Land Use Change

14.6.1 This is considered within the construction stage assessment in the Land Use Change section.

Embodied Carbon

14.6.2 It should be noted that in the absence of detailed vehicle movements for the operational phase of the project, the below referenced EPD's have been used to quantify A1-A5 life cycle stage emissions for replacement components during operation.

14.6.3 Both relevant EPD's state a reference service life (RSL) of 25 years (PV Modules) and 20 years (PCS inverters), respectively. As such it is anticipated that both the PV modules and inverters will need to be replaced once during the operational phase of the Project (37.5 years). It is assumed that this has taken place by year 26 of the Project's operation.

14.6.4 It is highly likely that by the point in future when planned maintenance replacement of PV modules and inverters is required, significant decarbonisation will have taken place across many sectors, such as manufacturing and transport. Noting this, to provide a conservative worst-case assumption, it has been assumed that maintenance replacement emits the same GHG emissions as was stated during construction for these Project components (A1-A3).

14.6.5 Unlike the construction stage, due to uncertainty with vehicle movements and site emissions during operation as stated above in 14.6.2, the EPD's provided for PV modules (EPD-Norway, 2024) and Inverters (Fraunhofer IBP, 2024), have also been utilised to quantify A1 – A5 stage emissions during the operational phase of the Project. Emissions factors for both EPD's have been provided below within Table 14.2.

Table 14.2: EPD Emissions factors A1 – A5.

EPD	Emissions factor	(A1 – A5)
PV Module	$kgCO_2e$ / Wp	0.38533

Inverters	$kgCO_2e$ per inverter unit	15,611

14.6.6 The above total factors stated within Table 14.2 was then applied to the maximum generation capacity of the Project that is assumed to be replaced once for PV modules (1,375 MWp) and total number of inverters required during construction (312), resulting in the following GHG emissions:

- PV Modules – 529,829 tCO_2e
- Inverters – 4,871 tCO_2e

14.6.7 This results in GHG emissions associated with the operation and maintenance period of the Project totalling 534,699 tCO_2e.

14.6.8 Any commitments relating to operation and maintenance of the Project have been secured within the Outline Operational Management Plan **[EN010147/APP/7.6.2]**, and are as follows:

a. Regular planned maintenance of the Project will be conducted to optimise efficiency of the Scheme infrastructure, such as replacement of PV modules and PCS, when required.

b. Increasing recyclability by segregating waste to be re-used and recycled were reasonably practicable.

c. Operating the Project in such a way as to minimise the creation of waste and maximise the use of alternative materials with lower embodied carbon such as locally sourced products and materials with a higher recycled content.

d. Encouraging the use of lower carbon modes of transport by identifying and communicating local bus connections and pedestrian and cycle access routes to/from the Scheme to all staff.

e. Switching off vehicles and plant when not in use and ensuring vehicles conform to current EU emissions standards.

Avoided Emissions

14.6.9 The 840 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 Project.

14.6.10 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 0.25692 $kgCO_2e/kWh$ (DESNZ, 2024) has been used as the baseline for this assessment, as

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

projected grid decarbonisation scenarios rely on the implementation of renewable energy generation that is provided by projects such as the Project.

14.6.11 The long run marginal figures (DESNZ, 2023), as explained in paragraph 14.4.5 have also been used within this assessment, alongside the current grid average figure, to present a potential range of carbon emissions saved in association with marginal generating source displacement as a result of the Project.

14.6.12 A range is provided as, while the current grid average figure is the only set figure available, it is a static figure that does not represent the likely scenario of an increasingly decarbonised grid over the Project's 37.5 year estimated operational lifespan. This represents no new renewable electricity abating fossil fuel generation in the grid. Whilst the long run marginal figures are dynamic and show year on year decarbonisation towards the UK's committed net zero 2050 pledge, it is only a future baseline projection and cannot be taken with certainty, hence, neither are perfect estimates. It is likely that the true value of emissions displaced from the national grid as a result of the Project will fall somewhere within this range, however, due to uncertainties such as future development of climate policy and targets for renewables deployment actually being met, a more precise estimation could not be considered robust.

14.6.13 The carbon intensity of the marginal generating source has been discussed in the future baseline conditions section from paragraph 14.4.3.

14.6.14 The annual energy output of the Project has been calculated assuming a load factor of 11.06%, as calculated from the Digest of UK Energy Statistics (DUKES) load factors for renewable electricity generation, taking an average of historic load factors for 2012 – 2023 (for Solar PV schemes (DESNZ & BEIS, 2024).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. 840 MW for the Project), 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 DUKES load factors data used is for schemes operating on an unchanged configuration basis. The percentage provided shows how much energy was generated compared to maximum possible generation, based on the generation and capacity of plants that were operational throughout the year.

14.6.15 The energy output calculation has also taken into consideration the degradation factor of the PV modules, assumed to be 0.4% per annum. This is in line with the degradation factor stated on the identified preferred PV module EPD, which has been used to inform this assessment. It states, 'to ensure a stable and reliable life cycle, the LR5 72HGD PV panel comes with a power warranty featuring linear degradation of no more than 0.4%' (EPD-Norway,2024).

14.6.16 It should be noted that as the reference service life on the above stated EPD is 25 years, it is assumed for the purposes of the assessment, that all panels have been replaced once by year 26 of operation. As such, from this point, the degradation factor has been reset, resulting in an increase in output.

14.6.17 Table 14.3 displays the expected annual energy generation and operational GHG effects for the Project, based on the current grid average figure of

0.25692 $kgCO_2e/kWh$ (DESNZ & DEFRA, 2024). Over the Project's 37.5 year operational lifetime it has been calculated to output 29,376,880 MWh, resulting in 7,547,508 tCO_2e avoided emissions when using the current grid average.

Table 14.3: Expected annual energy generation and operational GHG effects (current grid average)

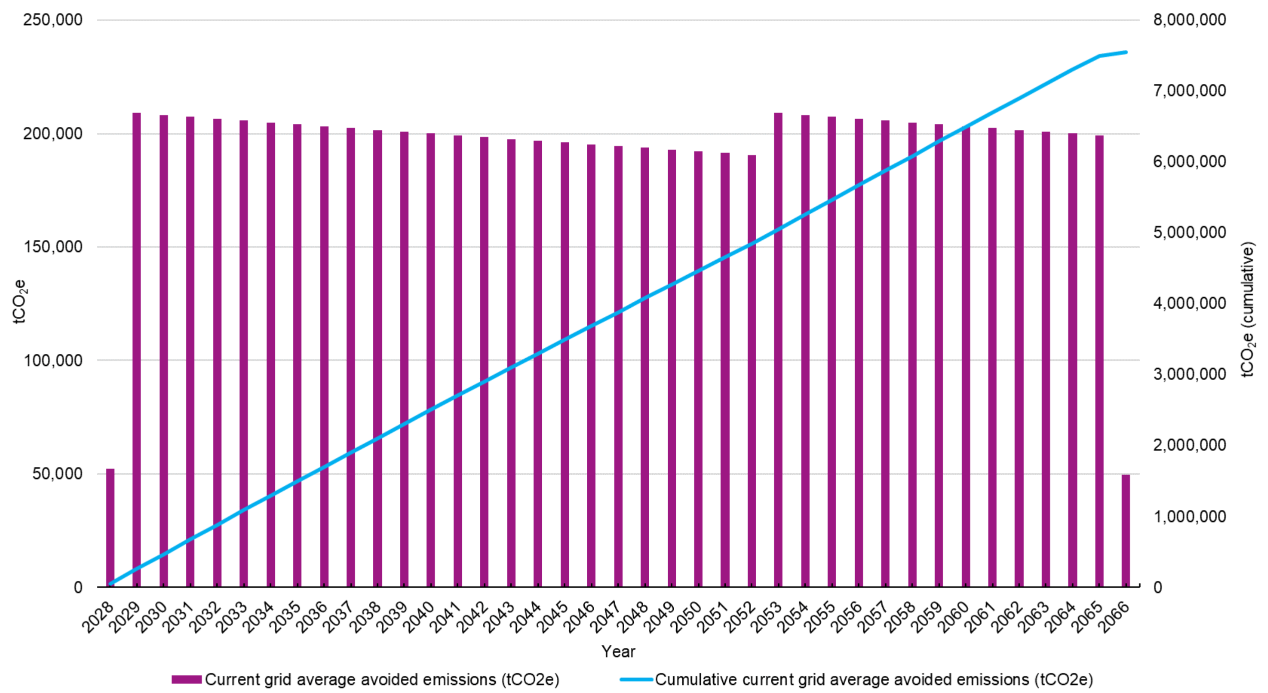
Year of Operation	Year	Output (MWh)	Current grid average avoided emissions (tCO_2e)	Cumulative current grid average avoided emissions (tCO_2e)
1*	2028	203,398	52,257	52,257
2	2029	813,594	209,029	261,286
3	2030	810,339	208,192	469,478
4	2031	807,098	207,360	676,838
5	2032	803,870	206,530	883,368
6	2033	800,654	205,704	1,089,072
7	2034	797,452	204,881	1,293,953
8	2035	794,262	204,062	1,498,015
9	2036	791,085	203,245	1,701,260
10	2037	787,920	202,432	1,903,693
11	2038	784,769	201,623	2,105,316
12	2039	781,630	200,816	2,306,132
13	2040	778,503	200,013	2,506,145
14	2041	775,389	199,213	2,705,358
15	2042	772,288	198,416	2,903,774
16	2043	769,198	197,622	3,101,396
17	2044	766,122	196,832	3,298,228
18	2045	763,057	196,045	3,494,273
19	2046	760,005	195,260	3,689,533
20	2047	756,965	194,479	3,884,013
21	2048	753,937	193,701	4,077,714
22	2049	750,921	192,927	4,270,641
23	2050	747,918	192,155	4,462,796
24	2051	744,926	191,386	4,654,182
25	2052	741,946	190,621	4,844,803
26	2053	813,594	209,029	5,053,832
27	2054	810,339	208,192	5,262,024
28	2055	807,098	207,360	5,469,384

Year of Operation	Year	Output (MWh)	Current grid average avoided emissions (tCO_2e)	Cumulative current grid average avoided emissions (tCO_2e)
29	2056	803,870	206,530	5,675,914
30	2057	800,654	205,704	5,881,618
31	2058	797,452	204,881	6,086,499
32	2059	794,262	204,062	6,290,561
33	2060	791,085	203,245	6,493,806
34	2061	787,920	202,432	6,696,239
35	2062	784,769	201,623	6,897,862
36	2063	781,630	200,816	7,098,678
37	2064	778,503	200,013	7,298,691
38	2065	775,389	199,213	7,497,904
39*	2066	193,072	49,604	7,547,508

* It should be noted that year 1 and year 39 accounts for only 3 months each (Oct, Nov, Dec in year 2028, Jan, Feb, March in year 2066).

14.6.18 Graph 2 offers a visual representation of Table 14.3, displaying the anticipated annual avoided emissions, and cumulative avoided emissions over the Project's lifetime under the current grid average scenario.

Graph 2: Annual and Cumulative GHG Impacts (current grid average)



14.6.19 Table 14.4 displays the expected annual energy generation and operational GHG effects for the Project, based on the long-run marginal figures (DESNZ, 2023). Over the Project's 37.5 year operational lifetime it has been calculated to output 29,376,880 MWh, resulting in 432,490 tCO_2e avoided emissions.

Table 14.4: Expected annual energy generation and operational GHG effects (DESNZ long-run marginal)

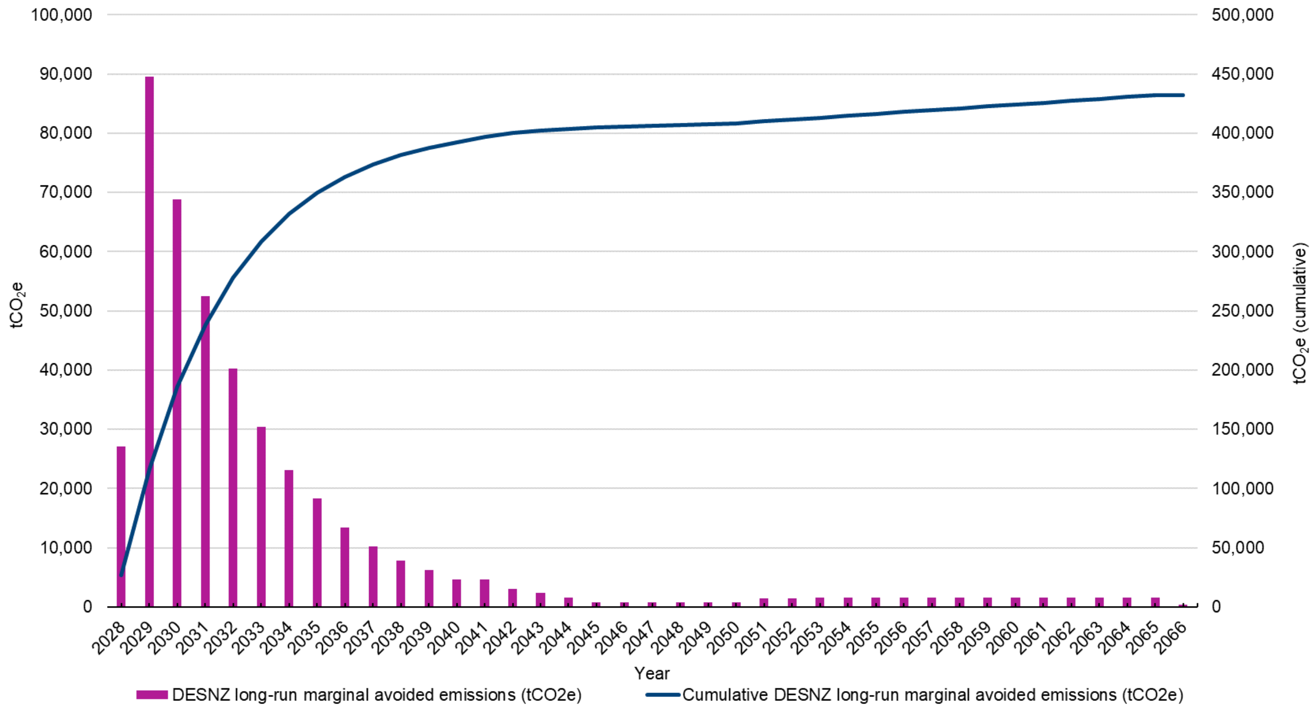
Year of Operation	Year	Output (MWh)	Long-run marginal avoided emissions (tCO_2e)	Cumulative long-run marginal avoided emissions (tCO_2e)
1*	2028	203,398	27,052	27,052
2	2029	813,594	89,495	116,547
3	2030	810,339	68,879	185,426
4	2031	807,098	52,461	237,888
5	2032	803,870	40,193	278,081
6	2033	800,654	30,425	308,506
7	2034	797,452	23,126	331,632
8	2035	794,262	18,268	349,900
9	2036	791,085	13,448	363,348
10	2037	787,920	10,243	373,591
11	2038	784,769	7,848	381,439
12	2039	781,630	6,253	387,692
13	2040	778,503	4,671	392,363
14	2041	775,389	4,652	397,015
15	2042	772,288	3,089	400,105
16	2043	769,198	2,308	402,412
17	2044	766,122	1,532	403,944
18	2045	763,057	763	404,708
19	2046	760,005	760	405,468
20	2047	756,965	757	406,224
21	2048	753,937	754	406,978
22	2049	750,921	751	407,729
23	2050	747,918	748	408,477
24	2051	744,926	1,490	409,967
25	2052	741,946	1,484	411,451
26	2053	813,594	1,627	413,078
27	2054	810,339	1,621	414,699
28	2055	807,098	1,614	416,313

Year of Operation	Year	Output (MWh)	Long-run marginal avoided emissions (tCO_2e)	Cumulative long-run marginal avoided emissions (tCO_2e)
29	2056	803,870	1,608	417,921
30	2057	800,654	1,601	419,522
31	2058	797,452	1,595	421,117
32	2059	794,262	1,589	422,706
33	2060	791,085	1,582	424,288
34	2061	787,920	1,576	425,864
35	2062	784,769	1,570	427,433
36	2063	781,630	1,563	428,996
37	2064	778,503	1,557	430,553
38	2065	775,389	1,551	432,104
39*	2066	193,072	386	432,490

* It should be noted that year 1 and year 39 accounts for only 3 months each (Oct, Nov, Dec in year 2028, Jan, Feb, March in year 2066).

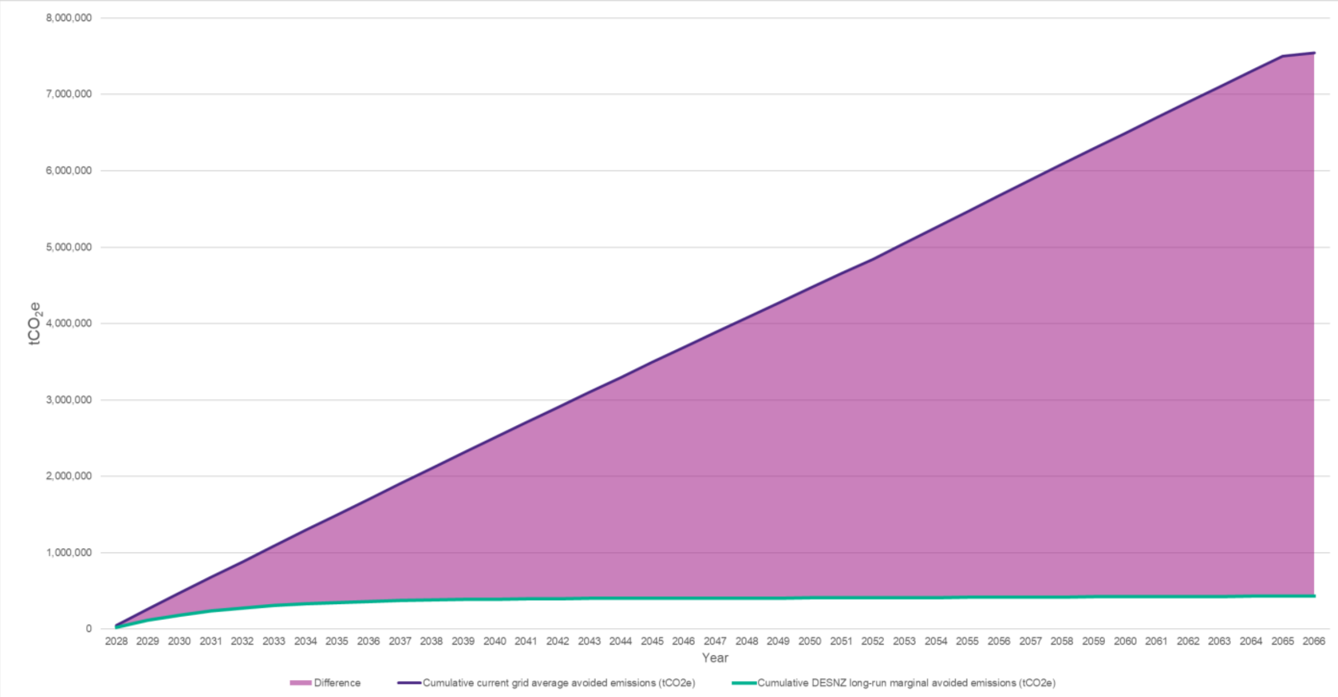
14.6.20 Graph 3 offers a visual representation of Table 14.4, displaying the anticipated annual avoided emissions, and cumulative avoided emissions over the Project's lifetime under the long-run marginal scenario (DESNZ, 2023).

Graph 3: Annual and Cumulative GHG impacts (DESNZ long-run marginal)



14.6.21 Graph 4 below displays the cumulative impact of both scenarios, with shading to highlight the difference, representing the potential range of avoided emissions that the Project's operation and maintenance phase will enable.

Graph 4: Current grid average and long-run marginal GHG emissions



14.7 Assessment of Decommissioning Effects on Climate Change

14.7.1 This section quantifies both the end-of-life stage emissions (C1-C4 and benefits and loads beyond the system boundaries (D stage), to present anticipated effects on climate change as a result of decommissioning the Project.

End-of-life stage emissions (C1-C4)

14.7.2 The following elements of the Projects C stage (end of life) emissions have been quantified:

- PV Modules
- PV Module Frames (Mounting structures and piles)
- Inverters

14.7.3 GHG emissions associated with PV modules, module frames, and inverters accounted for circa 85% of GHG emissions at construction stage. As such, these represent the most material consideration for decommissioning stage emissions for the Project with. remaining Project components providing immaterial contribution to GHG emissions.

14.7.4 The EPD provided for the PV modules (EPD-Norway,2024), states an emissions factor of 0.008732 $kgCO_2e/Wp$ related to C1-C4 stage emissions. this was scaled by the maximum generation capacity of the Project (1,375 MWp), and subsequently doubled to account for the process to take place twice, as panels are anticipated to be replaced once during the operational lifespan of the Project. This amounts to 24,013 tCO_2e.

14.7.5 The EPD provided for the PV module frames (IBU-EPD,2019) states an emissions factor of 2 $kgCO_2e$/tonne of material for the C3 life-cycle stage (waste processing for reuse, recovery or recycling). When scaled by the total weight of material required for PV module frames (38,183 tCO_2e), this amounts to 76 tCO_2e.

14.7.6 The EPD provided for the Inverters (Fraunhofer IBP, 2024) states an emissions factor of 615 $kgCO_2e$ per inverter for the end-of-life stage (C1-C4). Once scaled by the total amount of inverters required for the Project (312), this results in 192 tCO_2e.

14.7.7 In combination emissions from the above quantified C1-C4 stage emissions results in an additional 24,281 tCO_2e.

Benefits and Loads Beyond the System boundary (D stage)

14.7.8 Benefits from D stage emissions have been accounted for and estimated wherever a clear commitment to reuse, recycling / recovery potential has been including within the Outline Decommissioning Plan **[EN010147/APP/7.6.4]**.

14.7.9 Table 14.5: D stage emissions below outlines materials where a commitment has been taken, alongside D stage benefit, and associated emissions.

Table 14.5: D stage emissions

Project Component	Amount	Emissions factor	D stage emissions (tCO_2e)
PV Modules	2,750 MWp*	-0.0759 $kgCO_2e$/Wp	-208,725
Module Frames	38,183 t	-1.71 tCO_2e/t	-65,293
Steel Gates (regular and security gates)	35 t	-1.32 tCO_2e/t	-46
Steel Security Fence	7.1 t	-1.32 tCO_2e/t	-9

*Generation capacity of the Project (1,375 MWp), doubled to account for panel replacement.

14.7.10 As can be seen in Table 14.5, this results in -274,074 tCO_2e for the Project.

Total

14.7.11 Accounting for both C1-C4 stage emissions, and D stage emissions arising from the Project this results in net emissions of -249,984 tCO_2e during the decommissioning phase of the Project.

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