SUNNICA ENERGY FARM
DCO EXAMINATION

WRITTEN REPRESENTATION

ANNEX F – CARBON

SAY NO TO SUNNICA ACTION GROUP LTD

11 NOVEMBER 2022

Findings on the Proposed Sunnica Energy (Solar PV) Farm

Cranfield University

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Abstract

This report constitutes the findings of Cranfield's investigation into the Sunnica Solar PV Farm. It focuses on Sunnica's Environmental Statement 6.1 Chapter 6: Climate Change*, hereafter referred to in this report as **Sunnica ES**.

The chief findings are that:

1) Sunnica may have overestimated their energy output at 23.5 TWh, unless they are intending an installed capacity of at least 625 MWp.
2) Sunnica's methodology for calculating GHG (greenhouse gas) emissions throughout the lifecycle stages of the Scheme is not transparent and has led to an underestimation of the lifetime emissions of the scheme.

Applying reasonable estimations based upon the information published in the Sunnica ES, and making assumptions favourable to the scheme** when information is lacking, we conclude:

- The realistic energy output of the proposed scheme would be 17.7 TWh (based on a calculation using Global Solar Atlas, a solar estimation program provided by The World Bank). A 625 MWp scheme would be required to achieve Sunnica's quoted energy output of 23.2 TWh.
- We have recalculated the construction and operational emissions using the data provided in the Environmental Statement and fair assumptions. Our estimation for total emissions is higher than Sunnica's.

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* Sunnica Energy Farm EN010106 Vol 6 Environmental Statement 6.1 Chapter 6: Climate Change, 18 November 2021 version 00 (hereafter referred to throughout this report as **Sunnica ES** for brevity). Internally referenced as PD-038 for the purposes of this examination.

** Adopting this approach, we view our assessment as one of a reasonable case but not the 'reasonable worst case'.

- Our calculations for Net Savings (the difference between the lifetime emissions of the Scheme and carbon savings that it makes compared to the performance of the national grid) indicate that, save for those cases where the battery storage included in the Scheme is limited to a capacity less than 500MWh and a PV field size of greater than 625MWp with no battery replacements, the Scheme emits more carbon than it saves. Put another way, the scheme during its lifetime would constitute a net increase in GHG emissions.

Contents

1.0 Introduction

1.1 Our brief has been to review and comment upon the statements concerning energy and GHG savings of the Scheme in the information published by Sunnica, in particular, in the **Sunnica Environmental Statement [1]**. Any direct references to sections of the Sunnica ES will generally be presented in this report as: **(ES, Section number, Table or Figure number, as relevant)**.

1.2.1 In Summary, we have found that:

a) Sunnica overestimate the energy output of their scheme based on Energy output for given Global Horizontal Irradiance (GHI) of the Scheme location.

b) On the information presented, Sunnica has omitted to consider in their calculations the totality of the scheme and its constituent parts in calculating GHG emissions, and thus underestimate the overall emissions:

- Data is presented in the Sunnica ES, but at various points the document does not indicate how that data has been used to calculate the presented lifecycle emissions.
- In some instances, there is an omission of a Green House Gas (GHG) generating feature from the lifecycle emissions calculations. For example, no replacement rate nor calculation is undertaken for replacement of the lithium-ion batteries making up the battery energy storage system (BESS) during the operational stage. The BESS is a significant part of the scheme and a considerable contributor to the operational GHG emissions. In our attempts to properly quantify the operational GHG emissions, we have had to make reasonable assumptions as to the replacement rate for such batteries based on industry knowledge.

1.3 In the Environmental Statement, Sunnica make estimations for the Lifetime GHG Emissions of the Scheme. This is broken down into the following: Construction, Operation & Decommissioning. This is important because they use the emissions to justify the performance of the Scheme by:

a) **Comparing the Construction emissions with the UK Carbon budget**.

The Scheme's construction GHG emissions are compared with the UK Carbon Budget (4th period 2023-27, to coincide with the proposed 2-year construction period of Scheme). The calculations by Sunnica in respect of the scheme conclude that the annual construction emissions are less than 1% of the annualized UK carbon budget and are therefore considered to have a minor adverse effect on climate change (**ES: Section 6.8.12, Table 6-14, p6-26**).

b) **Comparing the Operational emissions with those of the National Grid in a "like for like" comparison** (9 gCO2e/kWh compared with the Grid's lowest predicted value over the 40-year lifecycle of the Scheme of 27 gCo2e/kWh).

Comparison of the Scheme's Operational GHG estimated emissions are based on 2021 data (9gCO2e/kWh) with operational emissions of the Grid (lowest predicted value of 27gCO2e/kWh) based on the Department for Business, Energy & Industrial Strategy 2019 data tables **[2]**.

c) **Comparison of lifetime emissions of the Scheme (GHG intensity of 29 gCO2e/kWh) which compares favourably with alternative forms of energy such as gas, nuclear and on/offshore wind** (GHG intensity range of 5 to 500 gCO2e/kWh)

The Scheme appears to compare favourably but 2013 data is used for the alternative forms of energy when more recent data would be more appropriate.

d) **A comparison of the Scheme's average Operational annual emissions with the UK Carbon Budget**, which Sunnica conclude as being of less than 1% significance (and therefore the effects of the Scheme can be considered low).

1.4 We have sought to verify how the calculations for the various emissions values are presented to justify the Scheme and conclusions drawn. In doing so, we have carried out our own assessment of energy output. The values obtained have then been used to calculate the Net Savings which are effectively the reduction in emissions that the Scheme makes over its lifetime when compared to the Grid.

1.5 To make our various energy and GHG estimations, we have started from "given" data in the Sunnica ES (shown below in bold **blue** font):

1.5.1 There is no indication of the field size (installed capacity of the solar farm in MWp) given in more recent Sunnica documentation but in earlier scoping documentation, it was indicated that the Scheme would allow for a generation capacity up to 500 MW, so we have based our initial estimations on **500MWp**[a] (see also **Appendix B**). In addition, we have verified what the actual field size would be required to achieve Sunnica's given estimated energy generation in year 1 (see next point) and then applied the same estimation methodology to that.

1.5.2 We are told that the "Energy generation" from the Scheme during the first year of operation is estimated to be **643,400 MWh**[(b)]

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a. Sunnica's Environmental Impact Assessment Scoping Report, March 2019 as prepared by AECOM Infrastructure &Environment UK refers to the Scheme being 500MWp in section 1.1.1 p1 (Appendix B).

b. ES Section 6.8.22, p 6-28, quoted value **is 643,361 MWh.**

1.5.3 A **0.55%**[c] degradation factor has been applied for each subsequent year, resulting in an estimated energy generation figure of **518,900 MWh**[d] in the final year of operation and hence a total energy generation figure of around **23.2 TWh**[d] over the **40-year**[e] assessed lifetime.

1.5.4 Total GHG emissions from the construction, operation, and decommissioning phases are estimated to be approximately: **452,000, 208,800 and 15,200 tCO_2e**[f], respectively. Overall, this equates to GHG emissions of approximately **676,000 tCO_2e**[f] over the assessed lifetime of the Scheme.

1.5.5 Based on the quoted total energy generation (23.2 TW) and the lifecycle GHG emissions of 676,008 tCO2e, the GHG intensity of the energy generated by the Scheme over its assessed lifetime is calculated as **29.19 grams of CO_2 equivalent per kWh or gCO_2e/kWh (ES: Section 6.8.28 p 6-29)**.

i.e. $$Lifetime\ GHG\ Emissions\ Intensity = \frac{total\ emissions\ of\ 676{,}008{,}000\ (gCO2e)}{total\ energy\ output\ \ of\ 23{,}157{,}296\ (kWh)}$$

$$= 29.19\ gCO_2e/kWh$$

(Sunnica's unrounded estimates have been given here to show exactly how this value was derived, hereafter it will be presented as **29 gCO_2e/kWh** for ease).

This is a much more realistic value compared to that presented in the previous PEIR documentation **[3]** prior to the consultation period (i.e. 6.87gCO2e/kWh) and demonstrates that embodied carbon during manufacture has now been considered in this value, as it compares more favourably with what is found in the literature. NREL's extensive review put the GHG emissions intensity of solar PV at 43gCO2e/kWh **[4, also Appendix C]** whereas, others cite the value at 20-25 gCO2e/kWh **[5, 6]**.

1.5.6 An operational GHG intensity of the Scheme is calculated as **9.02g CO2e/kWh** (based on operational emissions of 208,800 tCO2e (as above) and 23.2TW total energy generation. This is used to compare against the projected grid GHG intensity which

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c. 0.55% is an accepted value in the literature.

d. ES Section 6.8.22, p 6-28 quoted value is **518,850 MWh** in final year and **23,157,296 MWh** over the 40-year lifetime.

e. Traditionally, typical lifetime estimates in the literature are for 25-30 years but some commercial modules such as "SunPower" quote 40 years. Their webpage quotes "SunPower expects its modules (panels) have a useful life of more than 40 years, defined as 99% of modules producing at least 70% of their power"[redacted]

f. ES Section 6.8.27 Table 6-16, p6-29, quoted values are 452,015, 208,809 and 15,185 (for construction, operation and decommissioning respectively,) totalling 676,008 **tCO2e**

ES (**ES: Section 6.8.24, p6-28**) comments is projected to not fall below **27gCO2e/kWh** for operational emissions**.**

2.0 Solar Radiation Potential at Site (a recalculation of the Scheme's energy output)

2.1 The energy output from the plant has a significant impact on the reduction of GHG emissions, a larger energy output equating to a lower GHG emissions intensity (see equation above).

2.2 An assessment of the estimated solar photovoltaic (PV) power generation potential from Global Solar Atlas[g] and the Centre for Alternative Technology[h] (CAT) put the maximum long-term averages for periods between 1994 -2018 at the location of the Sunnica site around 1,100 kWh/kWp (See Figure 1).

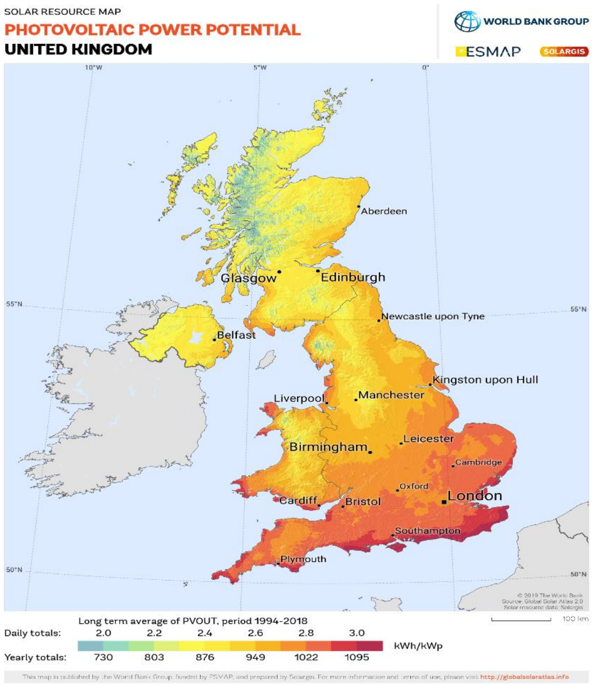

Figure 1 PV Power Potential in the UK [i]

2.3 "Global Solar Atlas" is an online solar resource that has been provided by the World Bank Group in 2017 as a free service to governments, developers and the general public. It enables the user to obtain solar data and carry out simple electricity output calculations for any location covered by their solar resource database **[7].** It is a well-recognised resource which falls within a group of such calculators commonly used by lifecycle analysist practitioners and the Government in the UK.

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g. The Global Solar Atlas (GSA) is a free, online, map-based application that provides information on solar resource and photovoltaic power potential globally" available at: [redacted]

h. Centre for Alternative Technology, available at [redacted]

2.4 Using Global Solar Atlas, at an optimum tilt angle for a more focused region near the Sunnica sites and using 500MWp as the only indication that we have been able to find in the Sunnica documentation, this shows the annual average power output from a 500MWp plant to be ≈ 492,000 MWh from an annual global tilted radiation value of 1,213 kWh/m^2 (**See Appendix D**).

2.5 Using 492,000 MWh as a starting figure (i.e. year 1) with 0.55% degradation per annum, the recalculated total energy from the plant over the 40-year lifespan is now **17.7 TWh**, a 25% reduction in energy output compared to Sunnica's estimate of **23.5 TWh**[d]. Figure 2 shows the total energy output from the plant over the 40-year lifespan of the project comparing Sunnica's estimate (dotted blue line) with that obtained using the Global Solar Atlas application (solid orange line).

Figure 2 Total Energy from Plant (comparison between Sunnica's estimates and recalculated values based on more realistic estimate for energy output in 1st year of operation obtained using Global Solar Atlas)

2.6 This will have a knock-on effect on the claimed total GHG reduction. To that end, we have recalculated emissions based on:

- a 500MWp field with a first-year output of 492,000MWh – as mentioned, we are not confident of the field size that Sunnica intend and only have 500 MWp based on earlier Sunnica documentation[a]. Therefore, we have estimated the field size that **will** deliver the required output (see next bullet point).
- a minimum 625 MWp field size based on the use of Global Solar Atlas to achieve Sunnica's quoted energy output of 643,400 MWh in the first year. This was also cross-checked with other energy resource calculators, PVGIS and SAM[j] which gave

[j] PVGIS is PhotoVoltaic Geographical Information System available [redacted]. SAM is System Advisor Model available at: https://sam.nrel.gov/

results within the same area i.e. 640,000 to 648,000 MWh, although SAM appears to give a lower figure at 540,000 MWh.

2.7 In our assessment of generating capacity, we have not attempted to quantify other losses which would be occasioned by the use of PV generally and the setting up of the Sunnica scheme in particular. Such general losses include those caused by the requirement to invert the DC current produced by PV modules to AC in the Grid (such losses can be up to 20%). Such inversion is required by any form of energy generation which outputs in DC. We have also not quantified the losses incurred in stepping up the voltage of the electricity produced. Again, this is required whenever generation is not at the voltage required for use in the Grid but is particularly of note in Sunnica's case as there are stages where stepping up occurs.

2.8 In respect of the specific features of Sunnica, we have not attempted to quantify the losses incurred in storage of any of the energy produced by the scheme in the BESS. We have also not quantified the losses incurred in transmitting the generated electricity from the various sites to the substation at Burwell.

2.9 These are all factors which mean the power available at the connection at Burwell substation will be further reduced below those figures cited above as the output for the PV modules. Our figures above should therefore not be taken as a reasonable worst case but an optimistic case position.

2.10 In addition to the above, it should be noted that these losses are multiplied when there is a requirement to go through more than one substation (or other piece of electrical infrastructure e.g. inverters, rectifiers, or transformers). Thus, these issues are exacerbated in Sunnica because the scheme is subdivided into separate areas with three separate battery storage locations. It is far less efficient to do this than to co-locate BESS in a single area with all the PV cells (as was the case in Cleve Hill, for example). Unfortunately, because of the lack of detail, we have had to assume where unclear in our calculations that Sunnica is one large field of PV cells and associated equipment. This is a favourable assumption for Sunnica: were the PV to be modelled in the split up way in which they are proposed, this would negatively affect both on its energy output and its GHG emissions (to which see below).

2.11 A further point to mention at this stage, is that it seems that a clearer indication of how a presumed 500 MWp plant could be accommodated on the allocated land area without affecting the projected energy output needs to be elaborated upon (**Appendix E).**

3.0 Lifecycle Green House Gas (GHG) emissions

3.1 Life cycle assessment (LCA) provides the "cradle-to-grave" view of the environmental burdens of a technology **[8 ,9 and 10]** . Figure 3 illustrates the upstream, operational and downstream lifecycle stages of a typical solar electricity generating system. (It should be noted that the BESS and connective cabling between sites is a consideration of this Scheme and therefore, the associated mining/material preparation, manufacture, installation/construction and decommissioning operations of these facilities should be taken into account as part of a full LCA at some stage).

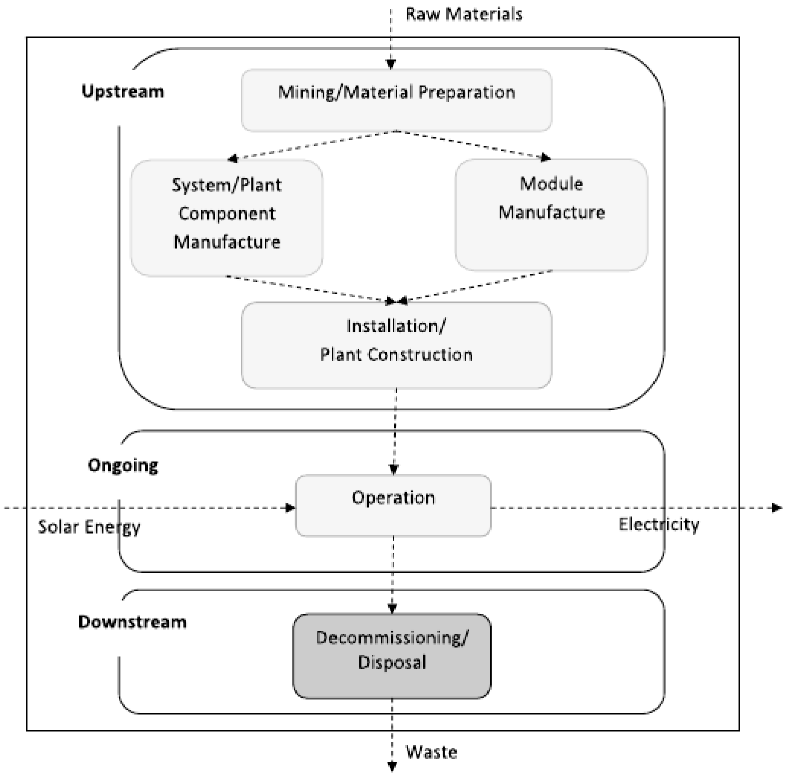


Figure 3 Lifecycle Stages of Solar PV System [10]

3.2 Studies dating from 2004 to 2014, evaluated the GHG emissions of PV plant to be within the range of 44 to 80 gCO_2e/kWh for different regions and technology employed in the PV system. Newer estimates, however, put the GHG footprint (harmonized data) between 20-25 gCO_2e/kWh **[5,6]** and an extensive NREL review (**see Appendix C**) puts the figure at 43gCO2e/kWh **[4].**

3.3 The estimate from Sunnica, at 29 gCO_2e/kWh for lifetime emissions is in line with the average harmonized data estimates for generalized schemes. However, various components required for the Sunnica scheme by reason of its location and stated requirement for downloading from as well as uploading electricity to the Grid have not been considered by Sunnica in estimating the GHG emissions at certain stages throughout the Scheme's lifecycle. For example:

3.3.1 Embodied carbon associated in transformers, module supports and cables is not included in the Table 1 below, which is a replication from the Sunnica ES on embodied energy benchmarks and emissions assumed in their estimations (**ES Section 6.3.18 Table 6-1, p6-5**)

NB: where tables are reproduced from Sunnica ES documentation, they are shown with ***green*** *headings, Cranfield reinterpretations are shown with* ***grey*** *headings.*

Table 1: Replication of Sunnica Environmental Statement Table 6-1: Embodied energy benchmarks and emissions intensities assumed *(ES Section 6.3.18, p6-5)*

Asset	Embodied energy/ GHG benchmark	Country	Emissions intensity
PV modules	N/a	UK	0.0103 $kgCO_2e$/ kWh generated in the first 30 years
PV inverters	210 kWh/ kW	Europe	0.295 $kgCO_2e$/ kWh rating
BESS inverters	210 kWh/ kW	China	0.57 $kgCO_2e$/ kWh rating
Switchgear	175 $kgCO_2e$/ kV	N/a	N/a
Li-ion batteries	155 $kgCO_2e$/ kWh	N/a	N/a

3.3.2 Batteries are not included in the list of replacement rates presented as being used to calculate GHG emissions during the operational phase (**ES section 6.3.21, p6-5**)

- Modules – 0.2%
- PV inverters – 4.4%
- BESS inverters – 3.1%
- Transformers – 1.8%
- Medium voltage (MV) switchgear – 0.8%
- Module structures – 0.1%

3.4 Given this and the fact that we feel that the energy output of the Scheme appears to have been over-estimated (if we assume a 500MWp PV field), the calculations by Sunnica of the GHG emissions need to be re-considered. The following discourse concerns estimations that we have made for:

a) A 500MWp field that delivers 17.7TWh. Again, it should be noted that the only reference that Sunnica make to field size of 500 MWp is in an earlier scoping document[a] but we have worked from that premise, given no other available data (see Section 4.0).

b) A 625MWp field that we estimate delivers the 23.2TWh stated by the Scheme (see Section 5.0).

3.5 In both field cases, we have used Sunnica's given data wherever possible and made assumptions which are favourable to Sunnica but which we regard as falling within a reasonable range of assumptions wherever data was unavailable. We have attempted to replicate how Sunnica made their GHG estimations. In adopting this rationale, we find that our GHG estimations are higher than Sunnica's. For the avoidance of doubt, we have not assessed this on a "reasonable worst case" basis. If the assumptions were made on a 'reasonable worst case' basis, our GHG estimations would be even higher than presented in this paper.

4.0 Estimated GHG emissions for 500MWp Field i.e. based on 17.7TWh output

4.1 We are of the view that a 500MWp field will not be able to deliver the claimed energy output of 23.2TWh in its lifetime (we estimate that a minimum size of field to achieve this would actually be 625MWp and we cover our GHG estimations for this in section 5). Our calculations indicate that 17.7TWh is more likely. A change in the energy output will cause a change in the associated GHG emissions as they are based on electrical output, thus it is necessary to re-calculate these to reflect the lower energy output.

4.2 Sunnica have calculated emissions based on the construction, operational and decommissioning stages of the Scheme's lifecycle. In our calculations, we have taken Sunnica's decommissioning emissions "as read" and concentrated on Construction and Operation emissions, where Sunnica have provided more information to work from. It should be noted that, aside from the issue of GHG emissions, appropriate recycling and disposal of the products used on site is important to understand and estimate to obtain the overall impact on the environment. While we do not assess this matter due to the limited information available, we note that safe disposal of PV modules and batteries can be difficult, costly, and damaging to the environment.

4.3 Re-estimation of Construction Emissions for a 500MWp field

4.3.1 Taking the issue of construction emissions first, Table 2 (below replicates the Construction GHG emissions given in the Sunnica documentation (**ES section 6.8.10 p6-25**)

Table 2: replication of ES Table 6-13: Construction GHG Emissions (ES section 6.8.10 p6-25)

Emissions Source	Emissions (tCO_2e)	% of Construction Emissions
Products	419,336	93%
Water use	<1	<1%
Fuel use	1,187	<1%
Transportation of materials & waste	18,761	4%
Worker transportation	8,099	2%
Waste treatment	4,631	1%
Total	**452,015**	**100%**

4.3.2 The catchall term "products" is used in the above table with little explanation as to what that includes. For our purposes, we have assumed that this includes components such as lithium-ion batteries, transformers and cabling etc. and that making several assumptions it should be possible to assign an estimated emissions value for each and to check whether we achieve a similar total emissions value. This can be done using the information provided in Table 1. Our assumptions are set out in the bullet points below. As has already been noted, these assumptions do not represent the reasonable worst case, and instead consider certain matters (identified in the points) favourably for Sunnica.

a. We assume PV modules to have an operational life of 30 years. Indeed, Sunnica in **ES, section 6.8.13, Table 6.1 p6-5** (shown in this report as Table 1) refer to an emissions intensity of "0.0103 kgCO2e/kWh generated in the first 30 years".
b. According to our calculations, starting at a year 1 energy output of 492,000MWh (from Global Solar Atlas) and 0.55% degradation per annum, the cumulative energy output at that stage is 13.638 TWh (this was obtained using an Excel spreadsheet included at **Appendix F**). According to **ES section 6.3.18 Table 6.1 p6-5**, the given emissions intensity is 0.0103kgCO2e/kWh generated in the first 30 years, therefore, total emissions = 13.638 TWh x 0.0103 kg/CO2e → 140,472 tCO2e after unit conversions.
c. We do not know what batteries are being used for the Scheme, so we have assumed a reasonable low to high power range of 500 to 1511MW (based on data reported by attendees at a meeting given by Sunnica at Redlodge, Suffolk on 9th March 2022 and the upper end of the range being extrapolated from other PV sites with BESS) and a C1 discharge rating i.e. 1hr, based on no other data being available. Consequently, our assumed storage capacity is 500 to 1511 MWh. In any event, because carbon intensity is measured by reference to MWh rather than MW, this is favourable for Sunnica. If instead the batteries are C2, using their carbon intensity figure that would further increase the amount of carbon embedded in the batteries. More information is needed to clarify this issue, but we make a best estimate using this favourable assumption.
d. A 13-year battery life has been assumed, based on Lithium Iron Phosphate (LFP) and the LFP-adaption Lithium Manganese Iron Phosphate (LMFP) technologies with cycle lives of 2000 up to 5,000[k] (**Appendix F**). Such a figure (i.e. 5000) represents a reasonable but favourable figure for Sunnica. Lower cycle times and another technology, lithium nickel manganese cobalt oxide, were considered and these presented lifespans of ≤5 years which lie closer to the reasonable worst case but has not been used here.
e. Transformers are assumed to be 20 units of 50MVA transformers[l] estimated to weigh 85 tonnes each, each at 53% steel and 14% copper as mentioned in **ES section 6.3.13**. Embodied carbon has been calculated using the Inventory of

k. Source: Battery University available at [redacted] ee Appendix F)

l. Source: Ampcontrol Group available at: [redacted] / (see Appendix F)

Carbon and Energy (ICE) database **[11]** as per **ES section 6.3.13 p6-4.** Recycled metals are assumed. (**Appendix F**)

f. Cables are assumed to be 11KV lines[m]. Recycled copper is assumed and the corresponding embodied carbon calculated using ICE **[11].** The calculations for cabling are shown in **Appendix F**. At the time of making our estimate, 11kV was chosen as the "best case" for Sunnica, especially as we didn't have the exact length of different kV cables that were being used in the Scheme. In our estimation, the cabling represents the least contributor to emissions (from the list of items that was considered, it was a factor of 1000 less than modules, inverters, batteries and switchgear). The calculation is shown in **Appendix G**.

g. Module structures have not been included in this list because Sunnica did not include them in construction emissions either and we were trying to replicate their estimations. (On the same reasoning, we also excluded them from our estimation of the Operational emissions). However, it should be noted that even excluding these, we have come close to Sunnica's estimation for construction emissions at the lower end of the battery power range we have used (i.e 397,251 tCO2e as per Table 3 below compared to 452,015 tCO2 in Table 2) but have exceeded it at the upper end of the range (553,956 tCO2e compared to 452,015tCO2e respectively). Module structures would add further to the GHG emissions.

4.3.3 Table 3 shows our estimations for the emissions related to "products" during the construction phase. **Appendix G** shows how the values in the last column have been achieved.

[m] Source: Thorne & Derrick International [redacted] pendix F)

Table 3: Cranfield's re-estimation of "Products" in Construction GHG emissions for 500MW field *(based on given embodied benchmarks and emissions intensities assumed by the Scheme)*

Asset	Embodied energy/ GHG benchmark	Country	Emissions intensity	Emission (tCO2e)
PV modules	N/a	UK	0.0103 $kgCO_2e$/ kWh generated in the first 30 years	140,472
PV inverters	210 kWh/ kW	Europe	0.295 $kgCO_2e$/ kWh rating	30,975
BESS inverters	210 kWh/ kW	China	0.57 $kgCO_2e$/ kWh rating	59,850
Switchgear	175 $kgCO_2e$/ kV	N/a	N/a	87,500
Li-ion batteries	155 $kgCO_2e$/ kWh	N/a	N/a	77,500 to 234,205 (range given because we have had to assume a low to high MWh scenario as no battery capacity information given in ES)
Module structures	Not included in this calculation by Sunnica, so not included by us.			
Transformers	20 units of 50MVA transformers[i], each at 53% steel and 14% copper (recycled metals assumed) **[11]**			697
Cables	11KV lines assumed & recycled copper **[11]**			257
	TOTAL "Products" in CONSTRUCTION GHG EMISSIONS:			**397,251 to 553,956**

Again, the total products is a "range" because a low to high MWh range has had to be assumed for batteries, in the light of the lack of data.

4.3.4 If the above value for "products" is now incorporated into Table 2, this gives Table 4:

Table 4: Cranfield's re-estimation of Construction GHG emissions for 500MW field

Emissions Source	Emissions (tCO_2e)	% of Construction Emissions
Products	397,251 to 553,956	93%
Water use	<1	<1%
Fuel use	1,187	<1%
Transportation of materials & waste	18,761	4%
Worker transportation	8,099	2%
Waste treatment	4,631	1%
Total	**429,548 to 586,253**	**100%**

4.3.5 The total for construction emissions now ranges from 429,548 to 586,253 tCO2e. The lower end of the range is fairly comparable to the value of 452,015 tCO2e given in Table 2 (i.e. the Scheme's estimated Construction GHG emissions).

4.4 Re-estimation of Operational Emissions for a 500MWp field (based on maintenance through replacement of components)

4.4.1 Next, looking at the Operational emissions, Table 5 is a replication from the Sunnica documentation (**ES section 6.8.17, Table 6-15, p6-27**) but with "inferred" lifetime emissions (in blue), based on the Schemes stated % of Operation Emissions. For example, 3% of total operational emissions of 208,809tCO2e for worker transportation implies 6,264 tCO2e etc.

Table 5: replication of ES Table 6-15: Operational GHG emissions (based on first year of operation with lifetime "inferred" emissions). (ES section 6.8.17, Table 6-15, p6-27)

Emissions Source	Emissions (tCO_2e)		% of Operation Emissions[13]
	1st year	"Inferred" Lifetime	
Worker transportation	199	6,264	3%
Maintenance	4,624	169,135	81%
Operation	909	33,409	16%

Total	**5,733**	**208,809**	**100%**

4.4.2 Looking at the maintenance figure alone (highlighted in the above table), it is possible to make an estimation of replacing certain components using Sunnica's quoted replacement rates listed on p8, taken from (**ES section 6.3.21, p6-5**), thus Table 6. Worked calculations are given in **Appendix G.**

Table 6: Cranfield estimation of GHG Operational Emissions for a 500MWp field due to maintenance based on Sunnica's given replacement rates for components over the Scheme's quoted 40-year lifecycle

Item	Emission (tCO2e) (see Table 3)	Given annual replacement rate (%)	Maintenance Emission (tCO2e)
PV Modules	140,472	0.2	11,238
PV Inverters	30,975	4.4	54,516
BESS Inverters	59,850	3.1	74,214
Switchgear	87,500	0.8	28,000
Lithium-ion batteries (500 – 1511MWh range considered	77,500-234,205	2 replacements (assuming 13-year lifespan)	155,000 to 468,410
Module structures	Not included in Sunnica's construction emissions, therefore, we assume also not considered in operational emissions. As we are trying to replicate Sunnica's methodology, we have also excluded them here.		
Transformers	697	1.8	13
		Total maintenance emissions:	**322,980 to 636,390**

4.4.3 The total maintenance emissions given above, 322,980 to 636,390 tCO2e varies significantly to that inferred from the given data as representative of the Scheme (Table 4) i.e. 169,135 tCO2e**.** When the additional items of worker transport and operation (as per Table 4) are also considered, the estimate for the Operational emissions rises to: 362,653 to 676,063 tCo2e**.** This equates to an operational GHG intensity of (362,653 to 676,063) divided by 17,705,211 i.e. 20.5 to 38.2 gCO2e/kWh.

4.4.4 Table 6 below gives the original Lifetime GHG emissions as presented in the Sunnica documentation (**ES section 6.8.27, Table 6-16, p 6-29**). This can now be modified to incorporate the re-estimations of these values.

Table 7: Re-interpretation of ES Table 6-16 giving original Lifetime GHG emissions as presented in Sunnica documentation and Cranfield's re-estimation of these same values for a 500MW field (ES section 6.8.27, Table 6-16, p 6-29)

Lifecycle Stage	Emissions (tCO_2e) as per Sunnica documentation	Emissions (tCO2e) as per Cranfield re-estimations
Construction	452,015	429,548 to 586,253
Operation	208,809	362,653 to 676,063
Decommissioning	15,185	15,185
Total	**676,008**	**807,386 to 1277,501**

4.4.5 This equates to a lifetime GHG Intensity value of (807,386 x 10^6 to 1277,501 x10^6 gCO2e) divided by 17,705,211,000 kWh i.e. 46 to 72 gCO2e/kWh.

5.0 Estimated GHG emissions for 625MWp field i.e. based on 23.2TWh output

5.1 Applying the same methodology as described above for the 500MWp field, estimations can be made to calculate the emissions associated with the 625MWp field that Cranfield have estimated will be able to deliver the Scheme's calculated output of 23.2TWh over its lifetime. (NB: This is based on an energy output in year 1 of 643,361 MWh, a 0.55% degradation rate for PV panels and 40 years lifecycle – as per Sunnica's calculations).

5.2 Re-estimation of Construction Emissions for 625MWp field

5.2.1 Table 8 below gives an estimation of construction emissions related to "products" used in the construction phase. Again, the same assumptions have been made (as per p10):

a. again, PV modules would have an expected life of 30 years, so the energy output at 30 years is 17.84 TWh, based on Sunnica's given year 1 output of 643,361 MWh and 0.55% degradation rate.
b. again, a storage capacity range of 500 to 1511 MWh has been assumed for Lithium-ion batteries.
c. Transformers are assumed to be 20 units of 50MVA transformers, each at 53% steel and 14% copper (recycled metals assumed) **[11]**
d. Cables are assumed to be 11KV lines & recycled copper **[11]**
e. Module structures again have not been included in this list. This is because we are trying to replicate Sunnica's methodology for estimating emissions – they did not include them in calculating construction emissions and therefore neither did we. By this reckoning, we have assumed that Sunnica did not include them in their calculations of operational emissions and therefore we have excluded them here too.

Table 8: Cranfield's re-estimation of "products" in Construction GHG emissions for 625MW field *(based on given embodied benchmarks and emissions intensities assumed by the Scheme)*

Asset	Embodied energy/ GHG benchmark	Country	Emissions intensity	Emission (tCO2e)
PV modules	N/a	UK	0.0103 $kgCO_2e$/ kWh generated in the first 30 years	183,728
PV inverters	210 kWh/ kW	Europe	0.295 $kgCO_2e$/ kWh rating	38,719
BESS inverters	210 kWh/ kW	China	0.57 $kgCO_2e$/ kWh rating	74,813
Switchgear	175 $kgCO_2e$/ kV	N/a	N/a	109,375
Li-ion batteries (500 to 1511 MWh)	155 $kgCO_2e$/ kWh	N/a	N/a	77,500 to 234,205
Module structures	Not included in this calculation (see reasoning above)			
Transformers	20 units of 50MVA transformers[l], each at 53% steel and 14% copper (recycled metals assumed) **[11]**			793
Cables	11KV lines assumed[m] & recycled copper **[11]**			257
	TOTAL "Products" in CONSTRUCTION GHG EMISSIONS			**485,185 to 641,890**

5.2.2 The workings behind the emissions value are similar to those presented for a 500 MW field as shown in **Appendix G**, replacing the field size with 625 MW where necessary. Again, these values can then be incorporated into Table 2 to give Table 9:

Table 9: Cranfield's re-estimation of Construction GHG emissions for 625MWp field

Emissions Source	Emissions (tCO_2e)	% of Construction Emissions
Products	485,185 to 641,890	93%
Water use	<1	<1%
Fuel use	1,187	<1%
Transportation of materials & waste	18,761	4%
Worker transportation	8,099	2%
Waste treatment	4,631	1%
Total	**517,863 to 674,568**	**100%**

5.3 Re-estimation of Operational emissions for 625MWp field

5.3.1 Table 10 shows our estimates for the maintenance component of operational emissions for a 625 MWp field.

Table 10: Cranfield estimation of GHG Operational Emissions due to maintenance for a 625MWp field based on Sunnica's given replacement rates for components over the Scheme's quoted 40-year lifecycle

Item	Emission (tCO2e) (see Table 3)	Given replacement rate (%)	Maintenance Emission (tCO2e)
PV Modules	183,728	0.2	14,698
PV Inverters	38,719	4.4	68,145
BESS Inverters	74,813	3.1	92,768
Switchgear	109,375	0.8	35,000
Lithium-ion batteries (500 to 1511MWh range considered	77,500-234,205	2 replacements	155,000 – 468,410
Module structures	Not included in this calculation		
Transformers	793	1.8	14
		Total "maintenance" emissions:	**365,626 to 679,036**

5.3.2 When the additional items of worker transport and operation (as per Table 4) are also taken into account, the estimate for the Operational emissions rises to: 405,299 to

718,709 tCo2e. An Operational GHG Intensity of (405,299 to 718,709) divided by23,157,295.58) = 17.5 to 31 gCO2e/kWh results.

5.3.3 Table 11 below gives the original Lifetime GHG emissions as presented in the Sunnica documentation (**ES section 6.8.27 Table 6-16, p 6-29**). This can now be modified to incorporate the re-estimations of these values.

Table 11: Re-interpretation of ES Table 6-16 giving original Lifetime GHG emissions as presented in Sunnica documentation and Cranfield's estimation for a 625MW field, which we feel will deliver Sunnica's estimated output

Lifecycle Stage	Emissions (tCO_2e) as per Sunnica ES documentation	Emissions (tCO2e) as per Cranfield re-estimations
Construction	452,015	517.863 to 674,568
Operation	208,809	405,299 to 718,709
Decommissioning	15,185	15,185
Total	**676,008**	**938,347 to 1,408,462**

5.3.4 This equates to a lifetime GHG intensity of (938,347 to 1,408,462 tCO2e) divided by 23,157,295.58 kWh i.e 40.52 to 60.8 g CO2e/KWh.

5.3.5 We are now able to make a comparison of our estimated GHG emissions with various forms of energy generation (as Sunnica have in their ES documentation - see p2 of this report).

6.0 Analysis of our estimated GHG emission results

6.1 Lifetime GHG Intensity values comparison with various forms of energy generation

6.1.1 The Scheme compares its lifetime GHG intensity (stated as 29 gCO2e/kWh) with alternative energy generation forms as shown below in Table 12, which is a replication of the Sunnica ES document Table 6-17 **(ES section 6.8.28 Table 6-17, p 6-29).**

Table 12: replication of ES Table 6-17: Comparison of lifetime energy intensities of various forms of energy generation (ES section 6.8.28 Table 6-17, p 6-29)

Energy Generation Type	GHG Intensity (gCO2e/kWh)
Combined Cycle Gas Turbine (CCGT)	380 to 500
Nuclear	5 to 55
Offshore Wind	5 to 24
Onshore Wind	7 to 20

6.1.2 Based on our previous estimations, we have produced the following (Table 13):

Table 13: Comparison of estimates for operational and lifetime GHG intensity *(a range is given because of the necessity of assuming a range for battery storage, as no battery capacity data is given)*

	Operational GHG Intensity (gCO2e/kWh)	Lifetime GHG Intensity (gCO2e/kWh)
Sunnica's estimation (500MWp): as per ES document	**9**	**29**
Cranfield (500 MWp)	**21 to 38**	**45 to 72**
Cranfield (625 MWp)	**18 to 31**	**41 to 61**

6.1.3 This shows that, according to our estimations, the Scheme as presented compares unfavourably with wind, less favourably with all but the higher end of GHG intensity for nuclear and favourably compares to fossil electricity generation (comparison of lifetime GHG Intensity in Table 13 with those presented in Table 12).

6.1.4 As has been noted above, estimates put the GHG footprint (harmonized data) varies, for example between 20-25 gCO2e/kWh [**5,6**] or 43 gCO2e/KWh in NREL's extensive review **[4, also Appendix C]**. Our estimates for the Scheme are considerably higher than Sunnica's i.e. ranging from 41 to 72 gCO2e/KWh (depending on PV field size and

BESS storage capacity) as compared to Sunnica's value of 29 gCO2e/KWh. It appears to us that a number of features lead to Sunnica being less efficient than other solar schemes:

- Sunnica has over 30 hectares of BESS across three separate sites. The associated GHGs in installing and replacing the batteries over the lifespan of the Scheme is significant. The splitting of the battery farms into 3 separate sites is also inefficient and increases GHG inoperability.
- The shape and design of Sunnica mean there are various sources of GHG which would be reduced if the solar generation was taken on one self-contained site (e.g. length of wiring, ancillary electrical equipment such as transformers, etc). Indeed, we have not been able to fully model Sunnica as designed and have made the favourable assumption where necessary that the scheme is one large self-contained field. Were it fully modelled as designed, this would have a further negative impact on our calculation of GHG emissions for the scheme.
- The level of solar irradiation in the chosen location is lower than available further south in the UK. An alternative location further south would lead to the site producing more power per hectare, which would improve its emissions values.

6.1.5 There may be further features we have not assessed which cause additional difficulties for the Sunnica scheme. These are noted elsewhere and not repeated here. This includes any revisions due to adopting Option 3 for the connection to the Grid at Burwell with revisions to plant and cabling.

6.2 Comparison of GHG Emissions and Offset over lifetime of Scheme

6.2.1 According to the energy output from the Scheme, there will be an associated GHG emission. This can be estimated using the following equation for any given period:

$$Energy\ emission\ (gCO2e) = energy\ output\ (kWh) \times GHG\ Intensity\ (\frac{gCO2e}{kWh})$$

6.2.2 When comparing with the predicted performance of electricity generation through the National Grid, the operational GHG intensity can be used, as has been shown in the Sunnica ES (they make the comparison of their estimated 9 gCO2e/kWh with the predicted National Grid "best" value of 27 gCO2e/kWh).

6.2.3 The GHG "offset" is a comparison between what the Scheme emits and what the National Grid is predicted to emit, for the generation of the same amount of electricity. It is effectively, the CO2 that is saved over time (i.e. not emitted), by not using the Grid.

$$GHG\ Offset\ (CO2e) = enerygy\ output(KWh)\ x\ GHG\ Intensity(Grid - Scheme)(\frac{CO2e}{kWh})$$

The cumulative GHG Offset can thus be calculated for the lifetime of the Scheme.

6.2.4 It is possible to compare the emissions performance of the Scheme based on the figures presented by Sunnica with the estimations that we have made and present these pictographically.

6.2.5 Based on Sunnica's estimations for the Scheme (an "assumed" 500MWp field with unknown battery capacity), the Cumulative offset and emissions can be calculated for the 40-year period of the Scheme's lifetime. The plot is shown in Fig. 4 and the corresponding spreadsheet used by us to make the calculations behind the plot (which are based on Sunnica's given figures i.e. Sunnica's energy output; Sunnica's construction, operational and decommissioning emissions; and, Sunnica's given operational intensity and a comparison with the Grid's operational intensity) is shown in **Appendix H**.

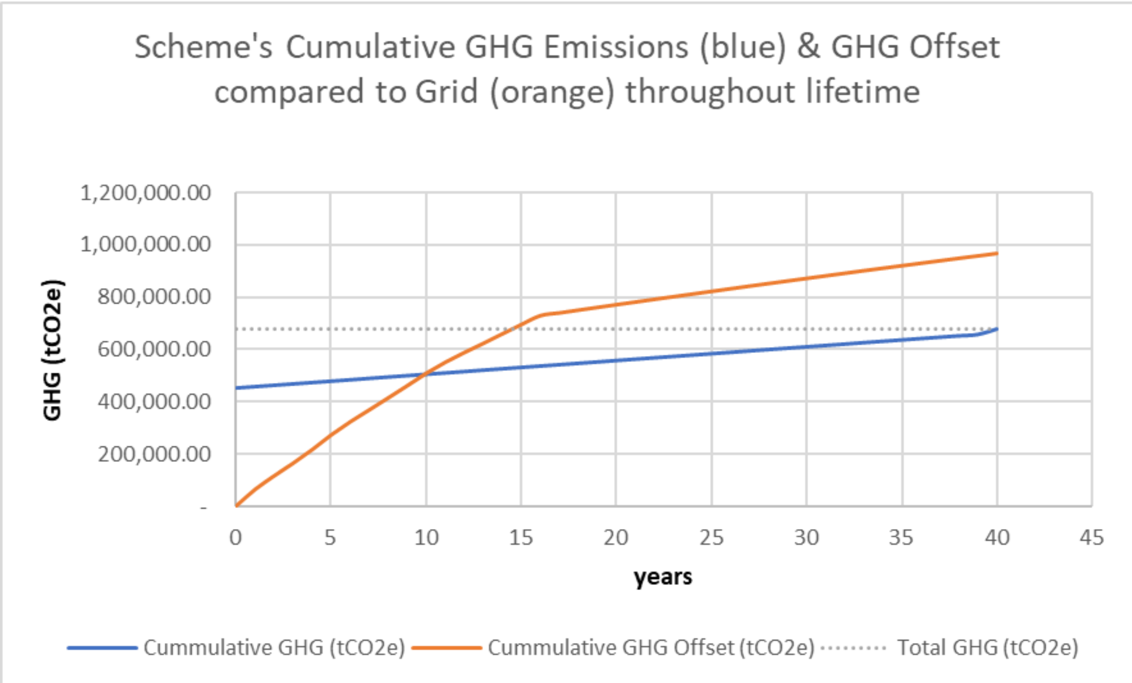


Fig 4 Comparison of Scheme's GHG Emissions and GHG Offset throughout lifetime (for an unknown field size and unknown battery capacity) based on Sunnica's given values (see Appendix H)

6.2.6 This plot based on Sunnica claims shows that emissions and offset overlap, seeking to demonstrate that the scheme is a "net-offsetter". At 10 years there is a complete offset between the construction emissions and the annualised operation emissions. An overlap of the GHG offset line and the Total GHG line (in this case at about 15 years) signifies net-zero is achieved over the lifespan of the scheme. However, we will go on to show that based on our assessment of the GHG emissions (using Sunnica's figures and making lenient assumptions for the batteries, transformers and cables where there is no available data), the plot is less optimistic than this.

6.2.7 It should be pointed out that the unusual "kink" in the orange offset curve at 17 years is due to the fact that, although we know that Sunnica compare the Scheme against the National Grid's operational GHG performance, we have no information on what scenario is being used **[12]** but we are told that the projected grid intensity is not projected to fall lower than an operational figure of 27 gCO2e/kWh (**ES section 6.8.24 p9-28**) and reference is made to the Dept of Business, Energy and Industrial Strategy (BEIS) data tables 1 to 19, dated 2019 **[2]**. So, we have used the (BEIS, 2019) values but have "bottomed-out" at 27 gCO2e/kWh (see spreadsheet presented in **Appendix H**, column 4).

6.2.8 However, based on our estimated year 1 output of 491,890 MWh for an assumed 500MWp field (and the lower end of our "range" for battery storage capacity of 500 MWh) and Sunnica's given 0.55% annual degradation factor due to the PV modules (which equates to a total output of 17.7 TWh), we achieve different results (Fig 5). The spreadsheet for this is shown in **Appendix I**.

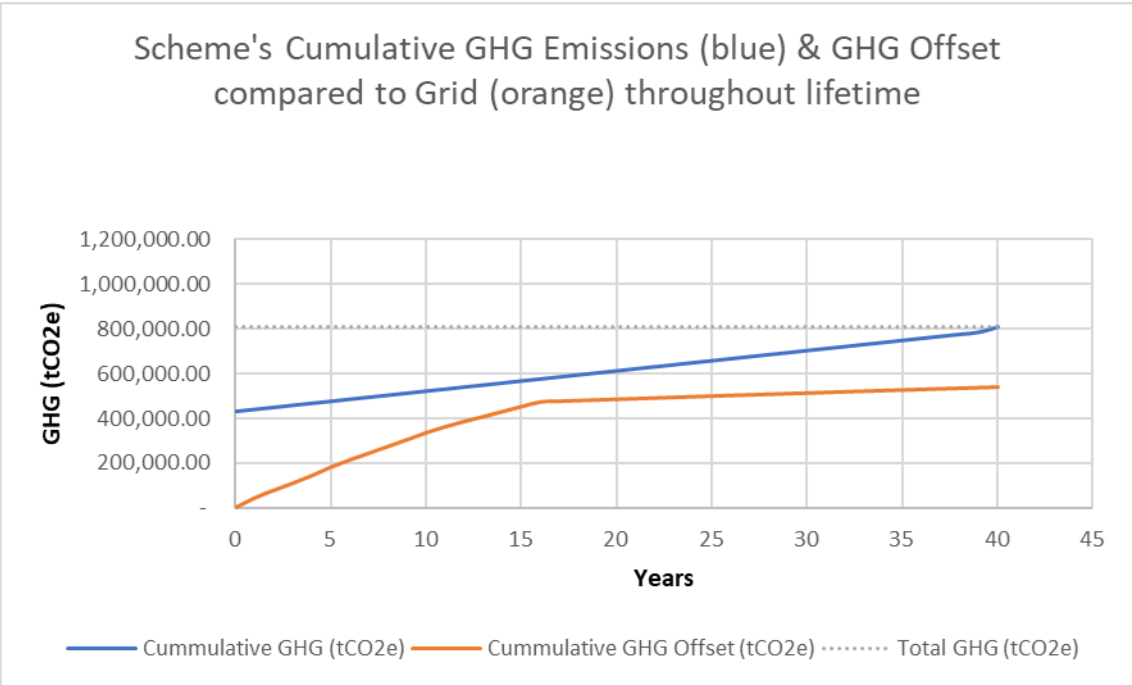
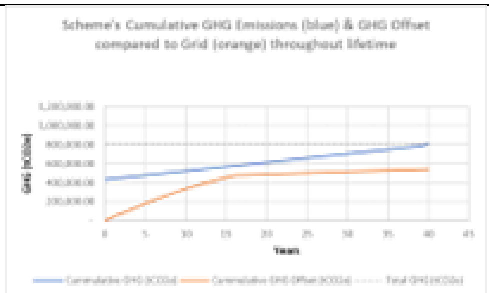
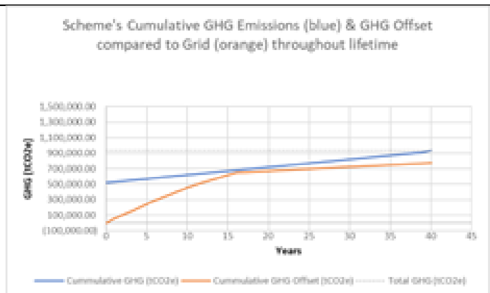
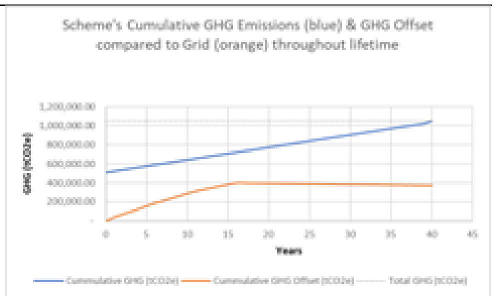
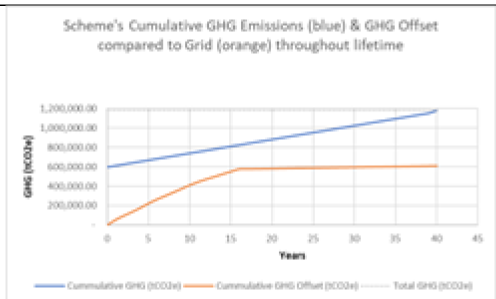
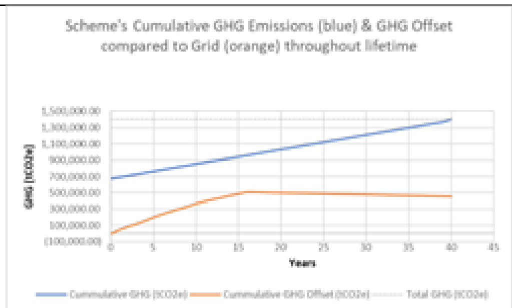


Fig 5. Comparison of Scheme's GHG Emissions and GHG Offset throughout lifetime (for a 500MWp field with 500MWh battery storage).

6.2.9 The key point to note here is that the lines for emissions and offset **do not** intersect nor do the offset and Total GHG. ***This means that, contrary to the claim by Sunnica, the Scheme cannot reach net-zero carbon emissions within its lifetime and is in fact a net-emitter of CO2.*** It should be stressed again, that we have achieved the plot in Fig 5, **using Sunnica's figures except for "favourable" assumptions** that we've had to make regarding batteries/transformers and cables, where no data was provided at the time.

6.2.10 Comparative emissions and offset graphs based on Cranfield's estimates for both 500 and 625 MWp fields and at battery storage capacities of 500, 1026 and 1511 MWh (representing low, medium and high ends of the range we have used) are shown collectively in Table 14. (It should be noted that the calculations behind these graphs factor in 2 battery replacements, in addition to the initially installed set, over the 40-year lifespan i.e. 13-year lifetime for batteries).

Table 14: Graphs of cumulative emissions and offsets vs time for different field sizes and battery capacities.

<table>
<tr><td></td><td colspan="2">Field size (MW)</td></tr>
<tr><td>Battery Capacity (MWh)</td><td>500</td><td>625</td></tr>
<tr><td>500</td><td></td><td>
</td></tr>
<tr><td>1026</td><td>
</td><td>
</td></tr>
<tr><td>1511</td><td></td><td>
</td></tr>
</table>

6.2.11 It can be seen from the above that for the lowest battery storage capacity (500 MWh) the two curves (emissions and offset) are at their closest but do not quite intersect. Thereafter, the curves move further apart with increasing battery storage capacity, meaning that the Scheme is increasingly a net-emitter, the greater the battery storage that is included. The curves appear to become closer with increasing field size for a given battery capacity. It seems to be that in order to cause an intersection i.e. become net-offsetter, the field size would need to be larger and the battery capacity smaller.

However, this is just in the context of the field size and battery capacity, there are other factors that might lead to the desirable intersection of the curves such as; poorer grid decarbonisation, the use of less carbon-embedded products in the Scheme and a higher GHI. On the other hand, as stated above there are various emitting sources which we have not assessed as part of the scheme which will lead Sunnica further away from the desirable intersection of the curves.

6.3 Net GHG Savings of the Scheme

6.3.1 The GHG "Net Savings" represent the difference between offset (or total GHG emissions savings i.e what has been saved by using the Scheme rather than the Grid for electricity generation) and lifecycle emissions of the Scheme i.e.

$$NET\ GHG\ Savings\ = Total\ GHG\ Emissions\ Savings\ (offset) - Total\ lifetime\ GHG\ emissions\ (tCO2e)$$

6.3.2 According to Table 7 – column 2 (or ES section 6.8.27 Table 6-16 p6-29) GHG emissions for Construction, Operation and Decommissioning and the given offset of **957,334 tCO2e** (ES section 6.8.25, p 6-28), the following calculations for net savings can be made based on Sunnica's estimations (Table 15).

Table 15: Net Savings calculation based on Sunnica's estimates

Lifecycle	**Offset (tCO2e)**	**Total Emissions (tCO2e)**	**Net-Savings (tCO2e)**
Construction	0	454,015	-452,015
Operation	957,334	208,809	748,525
Decommissioning	0	15,185	-15,185
		Total Net Savings:	**281,325**

So Net Savings for the Scheme as per Sunnica's estimates are **281,325 tCO2e** over the lifetime of the Scheme.

6.3.3 However, based on our calculations, we achieve the following Table 16, based on different field sizes, battery storage capacities and replacement rates for batteries (the results for the emissions calculations upon which these values are based are shown in **Appendix J**). It should be noted that:

- a 0% battery replacement, corresponds to installation of the initial battery field during construction with no replacement over the 40-year lifetime of the Scheme,
- 100% corresponds to initial set plus one replacement (so, 20-year battery lifetime)
- and 200% corresponds to initial set plus two replacements (equating to 13-year battery lifetime).
- Values in black type show a positive net-saving, those in red indicate a negative net-saving i.e. emission rather than saving.

6.3.4 It should be noted that Sunnica provide no detail on how they propose to use the BESS. Depending on the frequency of use, the batteries could be so degraded as to be functionally inoperable in far less than 10 years. The two replacements, each after 13 years that we've used, represents a favourable case. A reasonable worst case is a 5-year lifecycle and that the batteries are replaced 7 times throughout the lifetime of the scheme. If there is extensive uploading of energy from the Grid as well as downloading of energy to the Grid, this reasonable worse case could be even higher. As we have little detail on Sunnica's proposals, it is also not possible for us to know whether the batteries will be voluntarily changed as part of an upgrade scheme to a better technology.

Table 16: Cranfield calculations for Net Savings on GHG emissions (tCO2e) associated with different field size, battery storage capacities and battery replacement frequency

	500 MWp field			**625 MW field**		
	BESS Capacity (MWh)			**BESS capacity (MWh)**		
Battery replacement	**500**	**1026**	**1511**	**500**	**1026**	**1511**
0%	**40,625**	**-40,897**	**-116,072**	**144,375**	**62,845**	**-12,329**
100%	**-114,367**	**-358,957**	**-584,842**	**-10,624**	**-255,214**	**-480,739**
200%	**-269,367**	**-677,017**	**-1,052,892**	**-165,624**	**-573,274**	**-949,149**

6.3.5 Based on our calculations, Net savings can be made:

- with a 500 MWp field, only if the lower end of the battery storage capacity range is used and not replaced.
- with a 625 MWp field, only if the lower to mid-range battery storage capacity is used and not replaced.

6.3.6 Under all other circumstances considered where battery replacements are involved, net GHG emissions result rather than savings. If no replacement is done, even taking the very best case for Sunnica, the batteries would be functionally inoperable after 20 years. Observing the trend in the above table, it can be inferred that the Net Savings value becomes increasingly more negative (the Scheme "emits" rather than "saves") as the battery lifetime decreases and more sets are installed throughout the lifetime of the Scheme. **This implies that the Scheme is highly battery-lifetime dependant.**

6.3.7 In making this assessment, we have not considered wholesale replacement of the PV modules themselves. Such a replacement is possible if newer more efficient technology becomes available for such modules. It is impossible to make an assessment of the GHG emissions involved in such a replacement as we do not know the emissions intensity of new such technologies, nor how this would change the generating capacity of the scheme. However, for comparison, a complete replacement of the PV cells with the existing cells proposed in the ES by Sunnica would involve operational emissions of about 290,000 tCO2e as compared to 11,238 tCO2e using

Sunnica's given 0.2% annual replacement rate for PV modules (which appears to represent maintenance).

6.3.8 We have taken Sunnica's quoted decommissioning emissions as read, however, this might be investigated further.

6.4 Do our GHG estimates affect the performance criteria that Sunnica use?

6.4.1 In the ES document, the estimated performance of the Scheme's is judged by comparison of the emissions in the four following areas (see p1):

- Construction emissions compared to the UK carbon budget
- Operational emissions compared to those of the National Grid
- Lifetime emissions of the Scheme compared to those of alternative energies
- Average operational emissions of the Scheme compared with UK carbon budget

6.4.2 In section 6.4.21 of the ES document (**ES section 6.4.21, p 6-10**) it is commented that "in GHG accounting it is common practice to consider exclusion of emission sources that are <1% of a given emissions inventory on the basis of *de minimis* contribution". Two references are given to back this **[13, 14]** saying that emission sources of <1% contribution can be excluded. On further investigation of these two sources (dated 2012 and 2011 respectively, so not "current"), there is no specific mention of a 1% cap.

6.4.3 Comparison of construction emissions with carbon budget

6.4.3.1 The ES document makes a comparison of UK carbon budgets relevant to the construction period (**ES section 6.8.12, p 6-26**). This is shown in Table 17.

Table 17: Representation of ES document Table 6-14 (ES section 6.8.12, p 6-26) "UK carbon budgets relevant to construction period"

Relevant UK Carbon Budget	Annualised UK Carbon Budget (tCO_2e)	Annual Construction Emissions During Carbon Budget Period (tCO_2e)	Construction Emissions as a Proportion of Carbon Budget
4th Carbon Budget (2023 to 2027)	390,000,000	226,007	0.0580%

6.4.3.2 According to our estimations shown in **Appendix J**, we have (Table 18) which gives the relevant annual construction emissions for given field size and battery storage capacity. Note the construction period is 2 years, hence division by 2 to achieve annual emissions.

Table 18: "UK carbon budgets relevant to construction period" based on our GHG estimations

Field (MW) /Battery Capacity (MWh)	Associated Annual Construction Emissions During Carbon Budget Period (tCO2e)	Construction Emissions as a Proportion of Carbon Budget (390,000,000 tCO2e)
500/500	429,548/2 = 214,774	**0.055%**
500/1026	511,078/2 = 255,539	**0.065%**
500/1511	586,253/2 = 293,127	**0.075%**
625/500	517,863/2 = 258,932	**0.066%**
625/1026	599,393/2 = 299,697	**0.077%**
625/1511	674,568/2 = 337,284	**0.085%**

6.4.3.3 According to Sunnica's premise, all these emissions fall below the 1% significance level and would therefore be considered to have a minor adverse effect on the climate and are therefore acceptable. (**ES section 6.8.13, p 6-26**).

6.4.3.4 We are aware of no accepted principle in the industry which supports this approach. The size of the overall carbon budget is vast such that all but the most extreme constructions in size (consider, for example, the entire construction of HS2) would fall below the proposed 1% significance level. However, that does not mean that the emissions of all such structures should be ignored. Each construction and each scheme should be assessed on its own merits; in the context of energy generation, this is most appropriate to compare against the Grid emissions intensity. It should be noted that use of the carbon budget will almost entirely be made up of the sum of various emitters which are individually below the 1% significance level.

6.4.4 Operational emissions compared to performance of Grid in a "like for like" comparison

6.4.4.1 As previously mentioned, Sunnica have estimated an operational GHG intensity of 9 gCO2e/kWh as compared to the Grid's "best" operational value over the 40-year lifecycle of 27 gCO2e/kWh. Our calculations indicate that an operational value of 21 to 38 gCO2e/kWh (based on 500 to 1511 MWh battery storage capacity range) is likely. Sunnica's estimate is significantly lower than ours.

6.4.5 Comparison of lifetime emissions of Scheme with alternative forms of energy

6.4.5.1 Sunnica have presented a lifetime GHG intensity which compares favourably with alternative energy forms presenting a range between 5 to 500 gCO2e/kWh. However, our findings in Table 13, indicate that our estimation for the Scheme's lifetime emissions of 41 to 72 gCO2e/kWh (again dependant on field size and battery storage capacity) means that the Scheme compares unfavourably with wind energy generation, less favourably with all but the most inefficient nuclear, and compares favourably to fossil fuel generation (see Tables 12 and 13).

6.4.6 Comparison of Scheme's Operational annual emissions with UK Carbon budget

6.4.6.1 The ES document presents a table of the average annual operational GHG emissions of the Scheme vs the relevant UK carbon budgets relevant to the operation phase (up to 2037) (**ES section 6.8.29, p 6-30)**, see Table 19.

Table 19: Representation of ES document Table 6-18 (ES section 6.8.29, p 6-30): Average annual operational GHG emissions of the Scheme vs the relevant UK carbon budgets relevant to the operation phase (up to 2037)

Relevant UK Carbon Budget	Annualised UK Carbon Budget (tCO_2e)	Average Annual Operational Emissions vs the Grid During Carbon Budget Period (tCO_2e)	Operational Emissions as a Proportion of Carbon Budget
4th Carbon Budget (2023 to 2027)	390,000,000	5,695	0.0015%
5th Carbon Budget (2028 to 2032)	353,000,000	5,601	0.0016%
6th Carbon Budget (2033 to 2037)	193,000,000	5,281	0.0027%

6.4.6.2 The above is presumably based on an operational GHG intensity value of 9 gCO2e/kWh. Based on our estimations we can re-populate this table using Sunnica's quoted values above and our estimated operational GHG intensity value of 21 to 38 gCO2e/kWh for 500 MWp field (500 to 1511 MWh battery storage capacity) or 18 to 36 gCO2e/kWh for a 625 MWp field (500 to 1511 MWh), so 18 to 38g CO2e/kWh to cover the whole range (Table 20). (Although, the 3rd column in Table 19 indicates that it is the "offset" that is being considered, the actual numbers presented tally more with the annual operational emission of the Scheme).

Table 20: Our estimates of average annual operational GHG emissions of the Scheme vs the relevant UK carbon budgets relevant to the operation phase (up to 2037)

Relevant UK Carbon Budget	Annualised UK Carbon Budget (tCO2e)	Average Annual Operational Emissions (tCO2e) for 500 to 1511 MWh battery storage	Operational Emissions as a Proportion of Carbon Budget (%)
4th Carbon Budget (2023 to 2027)	390,000,000	11,390 – 24,045	0.0029 – 0.0061
5th Carbon Budget (2028 to 2032)	353,000,000	11,202 – 23,649	0.0029 – 0.0061
6th Carbon Budget (2033 to 2037)	193,000,000	10562 – 22,298	0.0027 – 0.0057

6.4.6.3 Again, according to Sunnica's reasoning, at less than 1%, the magnitude of the adverse effect is considered low in the context of carbon budgets that are available (out to 2037) (**ES section 6.8.30 p6-30**). As was already noted above, the providence of this approach to significance is not industry standard and is not something we have been able to verify. To approach carbon emission in this way would mean that all but the most extremely large projects fell below the 1% figure. Indeed, the use of the UK's carbon budget would almost entirely be taken up by construction and operation falling below the 1% threshold. Comparison to other forms of energy generation and the Grid is far more appropriate.

7.0 Conclusions

7.1 The main features to be drawn from the body of this report are that Sunnica's reasoning for the validity of the Scheme at this stage are very dependent on low GHG emissions. Sunnica have:

a) Overestimated their energy output (23.5 TWh) over 40 years.

b) Underestimated their GHG emissions.

The following points are made regarding:

7.2 Energy Output:

- Sunnica estimate 643,400 MWh in year 1. At an annual PV degradation rate of 0.55%, this equates to 23.2 TWh during the lifetime of the plant. (We have presumed that this is for a 500 MWp field based on an earlier Sunnica scoping document[a]).
- On the presumption of a 500 MWp field, work detailed here has come up with a more realistic energy output scenario using Global Solar Atlas of 17.7 TWh.
- Given that a 500 MW field is a presumption on our part and that there is no given field size in more recent Sunnica documentation, we estimate that in order to deliver Sunnica's quoted 643,400 MWh, a minimum field of about 625 MWp is required (according to Global Solar Atlas and other models).
- A more realistic (i.e. lower) output energy means a higher GHG intensity emission value (gCO_2e/kWh).
- It seems that a clearer indication of how a presumed 500 MWp plant could be accommodated on the allocated land area without affecting the projected energy output needs to be elaborated upon (**Appendix E).**

7.3 GHG Emissions:

7.3.1 We have used Sunnica's given data wherever possible and have made reasonable and favourable-to-Sunnica assumptions where no data was provided i.e. we have not assessed on a reasonable worst case.

7.3.2 Our findings are best compared against Sunnica's estimations using the following Table 21:

Table 21: Our comparisons with Sunnica's estimates for GHG emissions

Item	Sunnica's estimate	Our estimate for battery capacity of: 500 to 1511 MWh		Comment
		500 MWp	**625 MWp**	
Construction emissions (tCO2e)	452,015	429,548 to 586,253	517,863 to 674,568	**Lower end of our estimate reasonably comparable with Sunnica's.**
Operational emissions (tCO2e)	208,809	362,653 to 676,063	405,299 to 718,709	**Our estimates are higher than Sunnica's.**
Decommissioning emissions (tCO2e)	We have not investigated "decommissioning" and have accepted Sunnica's estimate of 15,185 as read. This may need further investigation.			
Lifetime emissions (tCO2e)	676,008	807,386 to 1277,501	938,347 to 1,408,462	**Our estimates are higher than Sunnica's.**
Operational GHG intensity (gCO2e/kWh)	9	21 to 38	18 to 31	**Our estimates are higher than Sunnica's.**
Lifetime GHG intensity (gCO2e/kWh)	29	45 to 72	41 to 61	**Our estimates are higher than Sunnica's.**

7.3.3 Comparing Scheme's GHG emissions and "offset":

Based on Sunnica's estimates (unknown field size of unknown battery storage capacity), net zero will be achieved in 15 years. According to our estimates (see Table 14), curves plotted for Scheme's emissions and the offset (which is the carbon savings made by the Scheme in comparison to the National Grid for a given quantity of electricity generation) show that the curves do not intersect, thus ***the Scheme does not reach net-zero in its lifetime and can be considered a carbon emitter***.

7.3.4 Net Savings on GHG emissions:

The GHG "Net Savings" represent the difference between offset (or total GHG emissions savings i.e what's been saved by using the Scheme rather than the Grid for electricity generation) and lifecycle emissions of the Scheme. According to Sunnica's estimates, net savings are 281,325 tCO_2e during the Scheme's lifetime. However, according to our estimations (Table 16):

- For a 500 MWp field: with the exception of a battery capacity of 500 MWh and no battery replacements during the lifetime of the plant, **net savings are negative and increasingly so, as battery replacements increase** (i.e. for shorter battery lifetimes).
- For a 625 MWp field: with the exception of 500 and 1026 MWh battery capacity with no battery replacements during the lifetime of the plant, **net savings are negative and increasingly so with shorter-life batteries.**

7.3.5 GHG estimates versus Sunnica's "performance" criteria:

i. **Construction emissions of Scheme versus the UK carbon budget:** our estimations for construction emissions fall below the 1% significance level and therefore, would be deemed of minor adverse effect according to Sunnica's premise. We do not accept that premise and would suggest such a comparison is an inapposite method of assessing the environmental impact of a scheme.

ii. **Operational emissions of Scheme compared to the performance of the National Grid:** Sunnica estimates an operational emissions intensity of 9 gCO_2e/kWh. Our estimates are much higher (500 to 1511 MWh battery capacity):

    500 MWp field: 21 to 38 gCO_2e/kWh

    625 MWp field: 18 to 36 gCO_2e/kWh

iii. **Comparison of lifetime emissions of Scheme with alternative energy forms:** Sunnica estimate a lifetime GHG intensity of 29 gCO_2e/kWh, whereas we estimate a range of 41 to 72 gCO_2e/kWh (depending on field size and battery capacity). The latter, indicates that the the Scheme compares particularly unfavourably with wind, less favourably with all but the most GHG intensive nuclear, and compares favourably to fossil fuel generation.

iv. **Comparison of Scheme's operation emissions versus UK carbon budget:** our estimations of operational emissions, although higher than Sunnica's, still fall below the 1% level in comparison to the UK carbon budget and as such would be deemed to have a minor adverse effect on climate, according to Sunnica's premise. Again, we do not accept this premise as noted above.

7.3.7 Based on our estimations and particularly noting that over time the decarbonisation of the grid is increasingly reducing its operational emissions against which we compare Sunnica we conclude, save in the specific circumstances above in 7.3.4, that the Scheme can never achieve net-zero within its lifetime. We find that the use of a 1% significance level for a net-emitting Scheme is questionable.

7.3.8 We note that, subsequent to the drafting of this report, Sunnica have made an application to modify the proposed scheme which has been accepted by the Examining Authority. Considering the scope of the changes, and the assumptions we have made generally (e.g. use of 11kV cabling throughout), we do not think this change alters our conclusions because we have assumed situations more favourable than the change. Even if the change does impact our GHG calculations, the impact is not material as the vast majority of GHG emissions do not come from the items that Sunnica has changed through its application

References:

[1] Sunnica **Energy Farm EN010106 Vol. 6 Environmental Statement, 6.1 Chapter 6: Climate Change version: 00 (18 November 2021)**

Planning Inspectorate Scheme Ref: EN010106, Application Document Ref: EN010106/APP/6.1, Sunnica Energy Farm Project Team, 18 November 2021

https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010106/EN010106-001781-SEF_ES_6.1_Chapter_6_Climate%20Change.pdf

Internally referenced as PD-038 for the purposes of this examination.

[2] Department for Business, Energy & Industrial Strategy (BEIS): Updated Energy and Emissions Projections 2018, April 2019

[3] Sunnica Energy Farm Preliminary Environmental Information Report (PEIR) Ch 6: Climate Change (August 2020) - this is one section of the larger SUNNICA ENERGY FARM Preliminary Environmental Information Report, Prepared by: AECOM Infrastructure & Environment UK Limited Unit 1 Wellbrook Court Girton Cambridge CB3 0NA United Kingdom T: +44 1223 488 000 aecom.com, [redacted]

[4] NREL, "Life Cycle Greenhouse Gas Emissions from Electricity Generation : Update": National Renewable Energy Laboratory, NREL/FS-6A50-80580, September 2021, available at: https://www.nrel.gov/docs/fy21osti/80580.pdf

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[6] J. H. C. Bosmans, L. C. Dammeier, and M. A. J. Huijbregts, "Greenhouse gas footprints of utility-scale photovoltaic facilities at the global scale OPEN ACCESS Greenhouse gas footprints of utility-scale photovoltaic facilities at the global scale," 2021.

[7] T. Larsen and S. Cox, "Renewable Energy GIS Tool Guide – Informing Choice of Tools to Support Decisions, NREL, https://www.nrel.gov/docs/fy19osti/74233.pdf

[8] NREL Harmonisation Project, "Life Cycle Greenhouse Gas Emissions from Solar Photovoltaics", NREL/FS-6A20-56487 • November 2012

[9] V. Muteri et al., "Review on Life Cycle Assessment of Solar Photovoltaic Panels", 2020

[10] D.D.Hsu et al., "Life Cycle Greenhouse Gas Emissions of Crystalline Silicon Photovoltaic Electricity Generation" Vol 16, 2012, doi: 10.1111/j.1530-9290.2011.00439.x

[11] Bath University and Circular Ecology, Inventory of Carbon and Energy (ICE) Database V3.0, 10 Nov 2019

[12] National Grid: Future Energy Scenarios 2019, https://www.nationalgrideso.com

[13] Department of Energy and Climate Change (DECC) EU Emissions Trading System "Guidance on Annual Verification for emissions from stationary installations" Version 6, February 2012

[14] BSI (British Standards Institute) PAS 2050: 2011. Specification for the Assessment of the Life Cycle Greenhouse Gas Emissions of Goods and Services. British Standards Institute, London. 2011

Appendix A: Biographies of authors

Prof Chris Sansom:

Professor Christopher Sansom gained his BSc from Liverpool University, and his PhD from Sussex University for research into the optical properties of infrared detectors. During a research career in industry and academia that has spanned over twenty-five years he has also gained two postgraduate diplomas, one in "Manufacturing Management and Technology" and a second in "Higher Education Teaching and Learning" and is a Black-Belt Six Sigma practitioner.

He is Professor of CSP (Concentrating Solar Power), and Lead the Zero Carbon Theme, at the University of Derby. After his PhD, he worked in research labs for Plessey, GEC, Marconi, and PerkinElmer, before entering Academia with Cranfield University where he remains a Visiting Professor. (Prior to 2021, he was the Professor of CSP and Head of the Centre for Renewable Energy Systems (CRES) at Cranfield). He has also been an Open University (OU) course tutor and Associate Lecturer for over 35 years. He is the sole UK representative on the EERA-Joint Committee on CSP which steers EU research in CSP and heads up the Line-Focus research group with the JC-CSP. He is a member of the International Solar Energy Society (ISES), a Fellow of the Higher Education Academy (FHEA), and a Fellow of the Royal Geographical Society (FRGS). He has considerable teaching experience and is a former MSc Course Director and lecturer on low carbon and renewable energy topics.

His current CSP research includes concentrating solar power for electrical power generation, solar collector characterisation and ageing evaluation, polymer films for solar power plant heliostats and line-focus solar collectors, linear Fresnel community-scale CSP, heliostat design and manufacture, solar thermal heating and cooling, solar-driven desalination and water purification, thermal storage, and nanostructured thermoelectric devices for energy harvesting. Within the broader "zero-carbon" field he is active in the decarbonisation of UK power generation (renewable energy, energy storage in particular), low carbon built environment and smart cities, carbon capture and storage, low carbon transport, as well as the environmental and social impact of zero-carbon technologies on local communities.

Dr Zaharadeen Hussaini:

Zaharaddeen Hussaini is a Researcher in CSP (Concentrating Solar Power) and a member of the Zero Carbon theme at the University of Derby. Zaharaddeen's first degree was in mechanical engineering from Bayero University, Nigeria. He then proceeded to attain his second degree in Sustainable Energy Engineering from the University of Nottingham before finally obtaining a PhD in CSP from Cranfield University.

Zaharaddeen has been closely associated with several CSP research projects right from his MSc, where an assessment of a Parabolic Trough CSP system for power generation was made in sub-Saharan Africa. In his PhD study, a novel Power Tower CSP system was developed that showed great potential for improving field efficiency and lowering the total system cost. As a PostDoc with the University of Cranfield, related research involved the UKRI-funded program to develop a zero-emission energy generation and storage system using Thermal Electric Generators (TEG) and a parabolic trough CSP system. Zaharaddeen has had several years of work experience in practical solar systems and acted as a consultant in Solar PV-related projects.

Current projects include Multi-Tower CSP development, large solar PV plant assessments and CSP for electrical power generation.

Dr Peter King:

Dr Peter King gained an MPhys from Oxford University and joined Cranfield on the MSc in Ultra Precision Technologies course. Following this course, he continued at Cranfield working on his PhD in the field of Concentrating Solar Power. On completing his thesis, titled "Form Measurement and Durability of Mirror Surfaces for Concentrating Solar Power Applications", he was appointed as a Research Fellow in Concentrating Solar Thermal Manufacturing at Cranfield.

Dr Peter King's current research is focused on the field of Concentrating Solar Power. His interests include assessment of solar collector shapes with ground and UAV based photogrammetry and the evaluation of mirror durability using sand erosion and simulated cleaning. He became an Academic Fellow in 2020 and is the Course Director for the MSc in Renewable Energy.

Dr Heather Almond:

Heather gained her BSc in Technology with Industrial Studies at Bristol Polytechnic in 1984 (with one year spent as a student-engineer with the Atomic Energy Authority) and her MSc in Advanced Manufacturing Technology at Cranfield University in 1986, after which she worked as a Development Engineer on the manufacture of Nuclear Magnetic Resonance scanners for Oxford Instruments Ltd for two years. She returned to Cranfield University to undertake her PhD, researching into the recovery of heavy metals from spent etching solutions, which she completed in 1995. She then worked at Nottingham University for two years, involved in Rapid Manufacturing and particularly the conversion of plastic rapid-prototyped artifacts to metal through investment casting.

She returned to Cranfield University in 1998 as a Research Fellow in non-conventional machining working on photochemical machining, electrolytic etching (as an alternative more environmentally friendly technique to etch complex components from exotic metals), micro electro-discharge machining and associated electroplating and forming techniques. In addition to her research, she lectured, supervised both MSc and PhD student projects and was the Course Director for Microsystems and Nanotechnology and Precision Engineering MSc courses and Learning Support Officer for the University.

Over the last 10 years at Cranfield University, she has been involved in research on Concentrating Solar Power (CSP), working in: erosion, durability and cleaning of mirrors, novel biomimicry-based concentrator systems, socio-economic aspects of siting CSP plant, gender-based issues in temperature-controlled environments, Building Integrated Solar Technologies and greenhouse gas emissions related to solar plant. She is currently a Research Fellow in the Centre for Renewable and Low Carbon Energy and, in addition to her research work, she lectures on: sustainability courses, mirror-durability, solar powered cooking and water treatment, non-conventional machining and supervises students. She is the Deputy Course Director of the MSc in Renewable Energy.

Appendix B: Indication of 500 MW Scheme in "Sunnica Energy Farm Environmental Impact Assessment Scoping Report, Sunnica Ltd., March 2019"

The following photos show the front cover of the SEF EIA Scoping Report dated March 2019 (Photo B1) and its associated p1, detailing section 1.1.1 (Photo B2). The last sentence of the latter comments that "The Scheme would allow for the generation, storage and export of up to 500 megawatts (MW) electrical generation capacity".

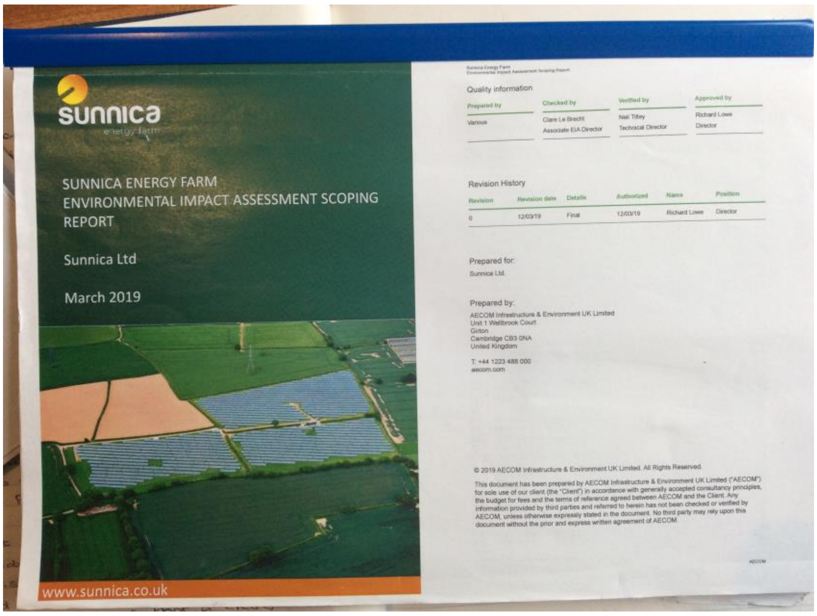


Photo B1: Front cover of the SEF EIA Scoping Report dated March 2019

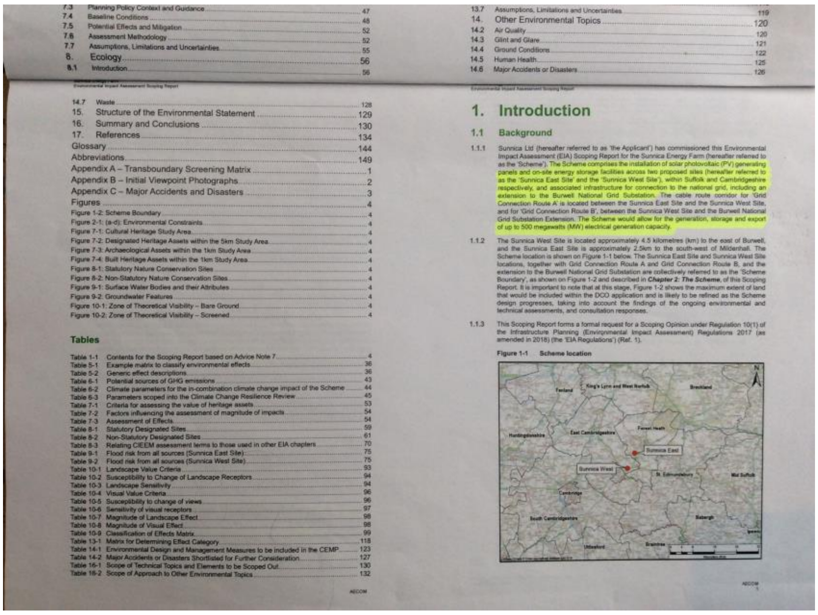
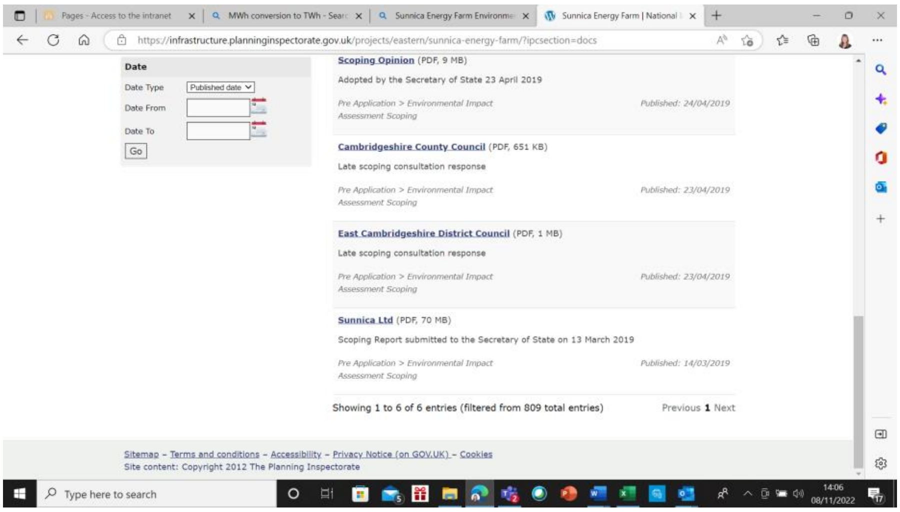


Photo B2: highlighting Section 1.1.1 of the SEF EIA Scoping Report dated March 2019

The Scoping Report (available on the National Infrastructure Planning website) was submitted to the Secretary of State 14th March 2019 as per the following screenshot:



Screenshot B: National Infrastructure Planning website detailing Scoping Report submission (last entry on page)

The National Infrastructure Planning website is available at: https://infrastructure.planninginspectorate.gov.uk/projects/eastern/sunnica-energy-farm/?ipcsection=docs

The specific document which is over 70MB in size is available at: https://infrastructure.planninginspectorate.gov.uk/wp-content/ipc/uploads/projects/EN010106/EN010106-000015-EN010106%20-%20Scoping%20Report.pdf (originally accessed: 5th August 2021)

Appendix C: Comparison of the GHG emissions with other utility scale electricity generation technologies.

NREL's systematic review of over 3,000 published articles on Life Cycle Analysis studies put the median GHG emissions intensity of Solar PV in the higher band when compared with other renewable energy technologies and nuclear energy [C1] (see Figure C). The median value for GHG emission intensity is given as 43gCO_2/kWh.

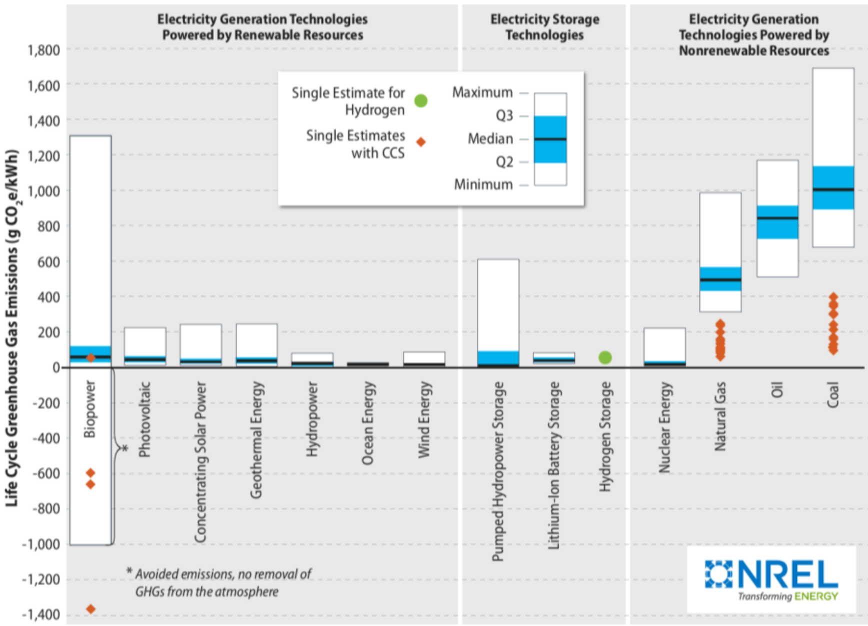


Figure C. Life cycle greenhouse gas emission estimates for selected electricity generation and storage [C1]

In Table C, a more thorough examination of the impact of a 500MW plant from solar PV, wind, hydro and nuclear power is examined given the referenced load factor of the technologies in the United Kingdom.

Table C. Load factor, GHG emissions, Lifespan, Electricity Generated and Net GHG emissions of different Renewable Energy Generation Technologies (calculated using excel spreadsheet)

Generation Technology	Load Factor	Median Total Life Cycle Emissions (gCO_2e/kWh) - NREL Estimates[C1]	Lifespan (Yrs.)	Electricity Generated Over Lifespan (MWh)	Net GHG Emissions Savings Over the Lifespan of the Technology (tCO_2e)
Solar Photovoltaic	11.20%[C2]	43	40	19,622,400.00	- 965,225.86
Wind Offshore	40.40%[C3]	13	25[C4]	44,238,000.00	1,086,308.33
Wind Onshore	26.60%[C3]	13	25[C5]	29,127,000.00	715,242.61
Hydro	35.20%[C6]]	21	50[C7]	77,088,000.00	-753,303.94
Nuclear	77.40%[C8]	13	40[C9]	135,604,800.00	1,465,887.89

Weather conditions can heavily influence load factors (especially in renewable energy), wind speeds on wind load factors, sun hours and battery storage for the load factor for solar PV and, to a lesser extent, rainfall on load factor for hydro. Table C hence only provides a demonstration of total collectable energy and net GHG emissions over the lifespan of the technology in the context of the United Kingdom-based on load factor performance in the year 2019 and NREL's median lifecycle emissions. **When NREL's median lifecycle emissions are adopted, and at a yearly load factor of 11.20%, solar PV performs poorer in regard to the total electricity generated over its lifespan when compared to the other generation technologies in the table. Similar performance with solar PV is observed in the net GHG emissions savings**. Here, at a GHG intensity of $43gCO_2e/kWh$, a net addition of 965,225.86 tCO_2e is instead added to the grid. This estimation follows the earlier assumption of grid decarbonization using National Grid's 'Two Degrees' Future Energy Scenarios (2019).

References:

[C1] NREL, "Life Cycle Greenhouse Gas Emissions from Electricity Generation : Update," 2021.

[C2] M. Jaganmohan, "Load factor of electricity from solar photovoltaics in the United Kingdom (UK) from 2010 to 2019," *Statista*, 2021. [Online]. Available: [redacted].

[C3] M. Jaganmohan, "Load factor of electricity from onshore and offshore wind in the United Kingdom (UK) from 2010 to 2019," *Statista*, 2021. [Online]. Available: [redacted]].

[C4] A. Spyroudi, "End-of-life planning in offshore wind," 2021.

[C5] M. Myers, “New research blows away claims that ageing wind farms are a bad investment,” *Imperial College Londin*, 2014. [Online]. Available: [redacted]

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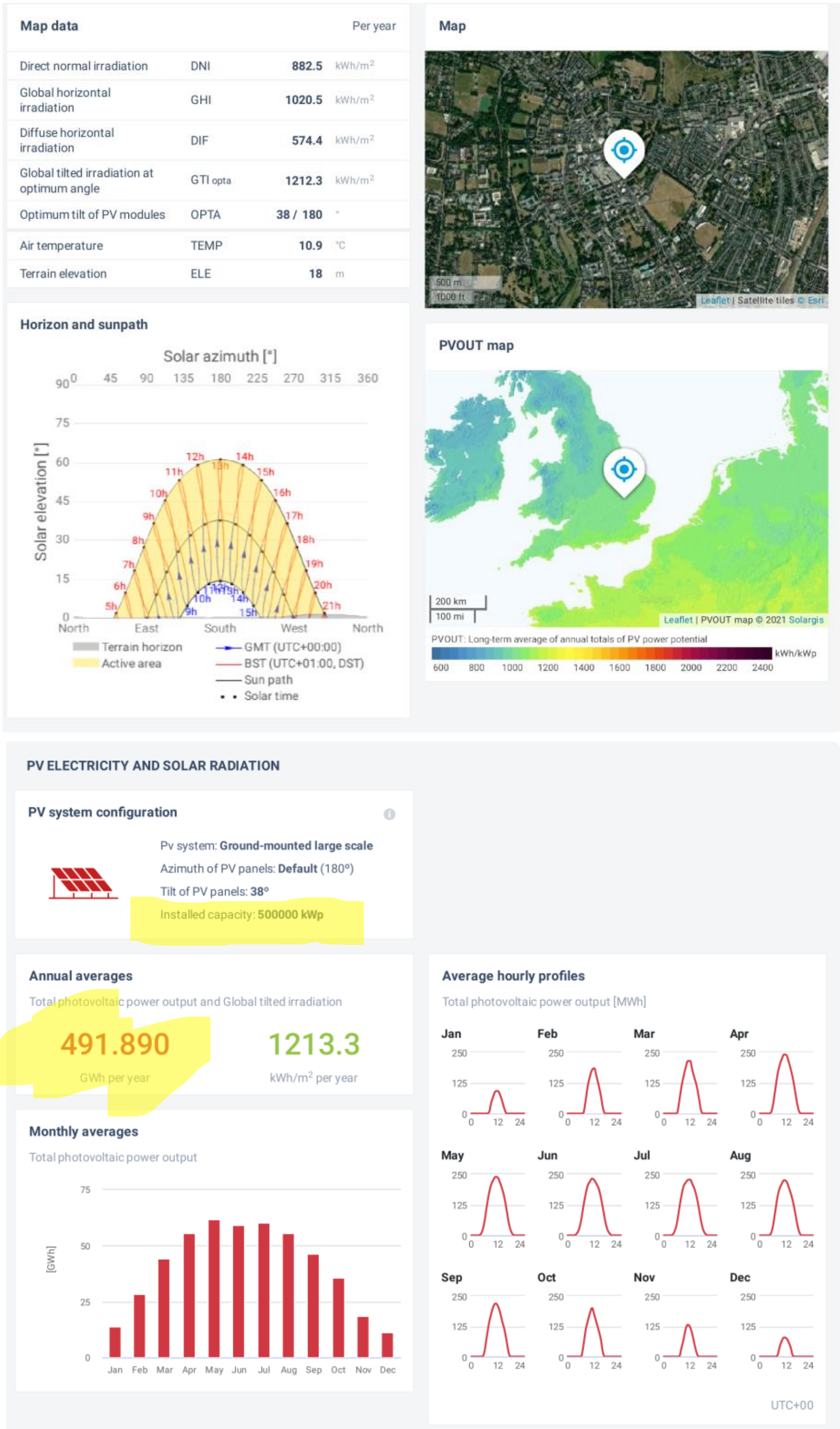
[C9] S. Novak and M. Podest, “Nuclear power plant ageing and life extension: Safety aspects An overview of issues and the IAEA’s symposium,” 2000.

Appendix D: Screenshot of Global Solar Atlas online map-based application as applied to Sunnica Scheme site (https://globalsolaratlas.info/map)



Highlighted areas represent given capacity of proposed plant and calculated power output resulting from use of that value.

Appendix E: Solar PV Land Requirements

For a typical solar installation, the general rule of thumb is that for every 1 MW of solar panels needed, a land area of 2 (ha) is required **[E1]–[E3]**. For the proposed 500MW field, a land area of 1,000 hectares is thus required. See Table E for the proposed layout for the scheme.

Table E. Proposed Sunnica Layout

Site	Solar Area (ha)	Other Land Area (ha)	Native Grassland (ha)	Ecology Enhancement Area (ha)	Battery Storage Area (ha)
Sunnica West A	256	2.51	26.35	13.86	9.00
Sunnica West B	23.00	22.26	-	92.48	-
Sunnica East A	115.00	22.86	-	92.81	7.00
Sunnica East B	227.00	33.48	-	56.87	17.00
Total	**621.00**	**81.11**	**26.35**	**256.03**	**33.0**

The data from Table E signifies that the land area allocated by Sunnica, 621ha, for the solar field would not meet the standard recommended sizing criteria. The draft National Policy on Renewable Energy has provided an updated range that guides the solar PV land requirements **[E4]**. The document outlines a different range for solar PV spacing with a wide range of 0.8 to 1.6 hectares per MW of output. Using those figures, the scheme would require a range of 400ha – 800ha for the 500MW plant. It is not exactly clear on which range the scheme stands.

A clearer indication of how 500MW would be achieved on the land allocated without affecting the projected energy output needs to be elaborated.

References:

[E1] J. Scurlock, "Solar photovoltaic electricity in agriculture – on your roofs and in your fields," 2013.

[E2] D. Palmer, R. Gottschalg, and T. Betts, "The future scope of large-scale solar in the UK : Site suitability and target analysis," *Renew. Energy*, vol. 133, pp. 1136–1146, 2019, doi: 10.1016/j.renene.2018.08.109.

[E3] International Finance Corporation, "Utility-Scale Solar Photovoltaic Power Plants," 2015.

[E4] Department of Energy and Climate Change (2021) Draft National Policy Statement for Renewable Energy Infrastructure [online]. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1015236/en-3-draft-for-consultation.pdf

Appendix F: Cranfield assumptions made in the calculation of emissions for various component parts of the PV Solar Field

PV modules

Excel spreadsheet for calculation of annual energy output given 0.55% annual degradation rate of PV modules

Year	Calculated Energy from Plant given 0.55% annual degradation rate (MWh)	Calculated Cummulative Energy from Plant (MWh)
1	491,890.00	491,890
2	489,184.61	981,075
3	486,494.09	1,467,569
4	483,818.37	1,951,387
5	481,157.37	2,432,544
6	478,511.01	2,911,055
7	475,879.20	3,386,935
8	473,261.86	3,860,196
9	470,658.92	4,330,855
10	468,070.30	4,798,926
11	465,495.91	5,264,422
12	462,935.68	5,727,357
13	460,389.53	6,187,747
14	457,857.39	6,645,604
15	455,339.18	7,100,943
16	452,834.81	7,553,778
17	450,344.22	8,004,122
18	447,867.33	8,451,990
19	445,404.06	8,897,394
20	442,954.33	9,340,348
21	440,518.09	9,780,866
22	438,095.24	10,218,961
23	435,685.71	10,654,647
24	433,289.44	11,087,937
25	430,906.35	11,518,843
26	428,536.36	11,947,379
27	426,179.41	12,373,559
28	423,835.43	12,797,394
29	421,504.33	13,218,899
30	419,186.06	13,638,085
31	416,880.53	14,054,965
32	414,587.69	14,469,553
33	412,307.46	14,881,860
34	410,039.77	15,291,900
35	407,784.55	15,699,685
36	405,541.73	16,105,226
37	403,311.26	16,508,538
38	401,093.04	16,909,631
39	398,887.03	17,308,518
40	396,693.15	17,705,211
Total:	17,705,211	17,705,211

- Estimated energy from plant in year 1 = 491,890 MWh (from Global Solar Atlas, see **Appendix D**)

- Calculated energy from plant in any year =

  previous year's energy output x 0.55%

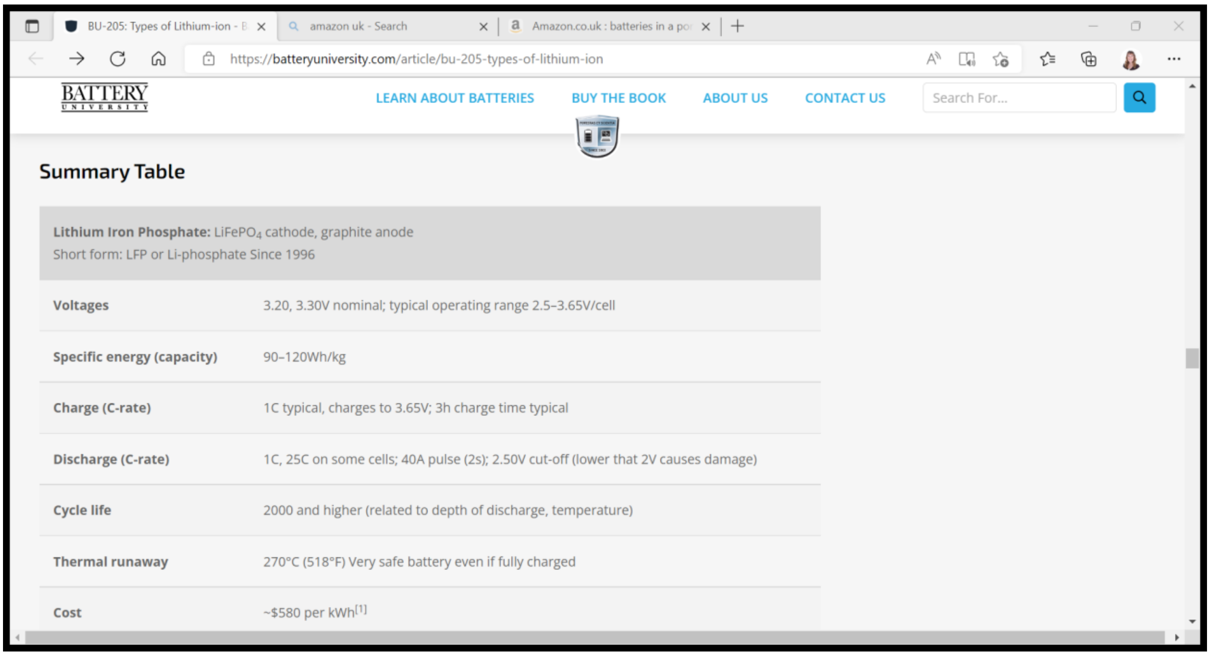
  - Assuming 30-year lifespan for PV modules as **per ES, section 6.8.13, Table 6.1** (where emissions intensity of "0.0103 kgCO2e/kWh generated in the first 30 years" is given). This is more favourable than taking the energy output at the proposed 40 years of the Scheme from an emissions perspective.

  - By year 30, the cumulative total for energy from the plant is 13,638,085 MWh = 13,638 TWh (highlighted in yellow)

Batteries

Screenshots of battery details taken at 28th August 2022 from Battery University available at: [redacted] (accessed 28th August 2022)

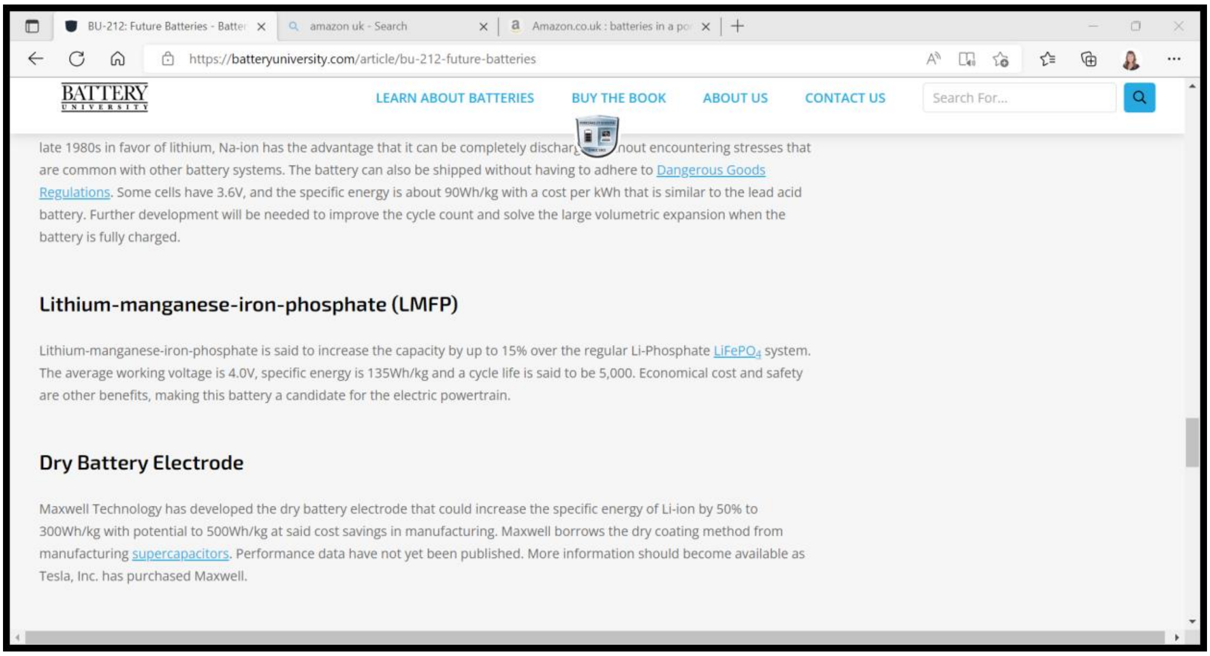
1. Battery details for Lithium Iron Phosphate (LFP):



Summary Table

Lithium Iron Phosphate: $LiFePO_4$ cathode, graphite anode Short form: LFP or Li-phosphate Since 1996	
Voltages	3.20, 3.30V nominal; typical operating range 2.5–3.65V/cell
Specific energy (capacity)	90–120Wh/kg
Charge (C-rate)	1C typical, charges to 3.65V; 3h charge time typical
Discharge (C-rate)	1C, 25C on some cells; 40A pulse (2s); 2.50V cut-off (lower that 2V causes damage)
Cycle life	2000 and higher (related to depth of discharge, temperature)
Thermal runaway	270°C (518°F) Very safe battery even if fully charged
Cost	~$580 per kWh[1]

2. Battery details for Lithium Manganese Iron Phosphate (LMFP)



late 1980s in favor of lithium, Na-ion has the advantage that it can be completely dischar[...]hout encountering stresses that are common with other battery systems. The battery can also be shipped without having to adhere to Dangerous Goods Regulations. Some cells have 3.6V, and the specific energy is about 90Wh/kg with a cost per kWh that is similar to the lead acid battery. Further development will be needed to improve the cycle count and solve the large volumetric expansion when the battery is fully charged.

Lithium-manganese-iron-phosphate (LMFP)

Lithium-manganese-iron-phosphate is said to increase the capacity by up to 15% over the regular Li-Phosphate $LiFePO_4$ system. The average working voltage is 4.0V, specific energy is 135Wh/kg and a cycle life is said to be 5,000. Economical cost and safety are other benefits, making this battery a candidate for the electric powertrain.

Dry Battery Electrode

Maxwell Technology has developed the dry battery electrode that could increase the specific energy of Li-ion by 50% to 300Wh/kg with potential to 500Wh/kg at said cost savings in manufacturing. Maxwell borrows the dry coating method from manufacturing supercapacitors. Performance data have not yet been published. More information should become available as Tesla, Inc. has purchased Maxwell.

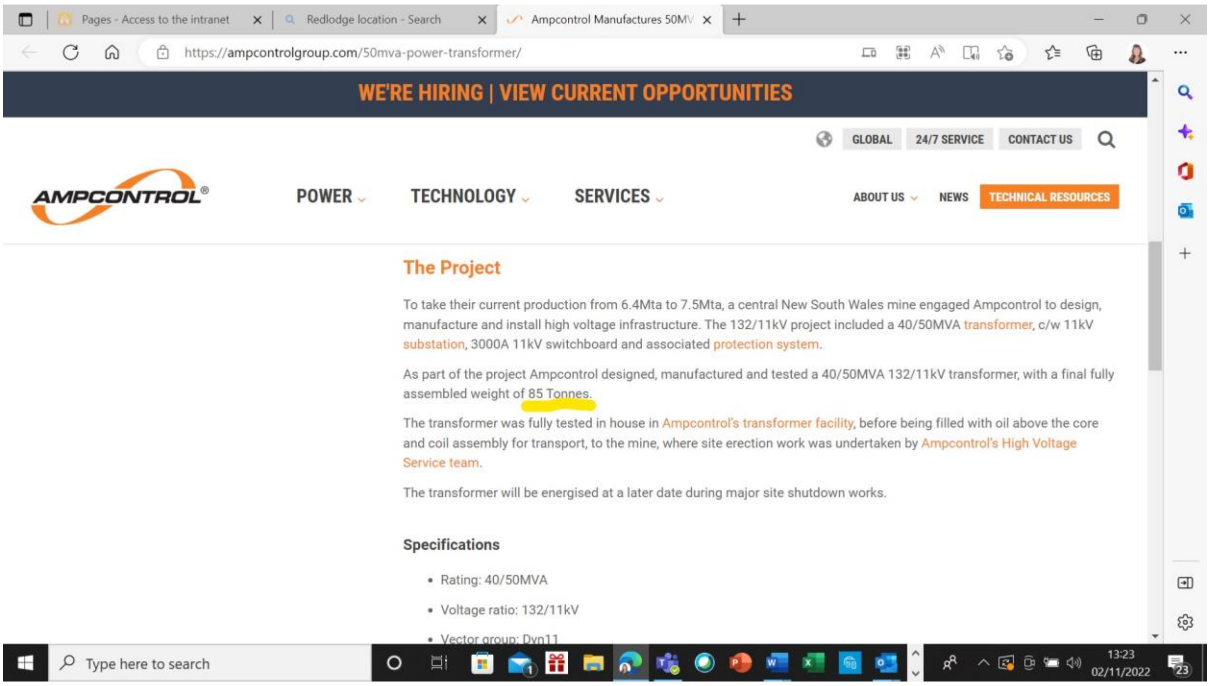
It can be seen that these similar technologies represent cycle lifetimes of between 2000-5000.

2000 to 5000 cycles divided by 365 days per year = 5.5 to 13.7 years

As we have no information on the types of batteries that will be used in the Scheme, we have selected the more favourable to Sunnica figure of 5000 i.e. **a lifetime of approximately 13 years.**

Transformers

On the website [redacted]) a 50MVA transformer is estimated to weigh 85,000kg as per following screenshot.



We are assuming 20 units of transformers (500MVA for the field and 500MVA for the BESS). According to Sunnica ES Section 6.3.13, a transformer is 52.7% steel and 13.8% copper. According to ICE **[11, also Ref 6-4 in Sunnica ES]:**

Recycled steel embodied carbon is 0.47 kgCO2e/kg

Recycled copper embodied carbon is 0.84 kgCO2e/kg

Therefore,

Embodied carbon for steel in transformers is: 20 units x 85,000 kg x 52.7% x 0.47 kgCO2e/kg = 421073 Kg

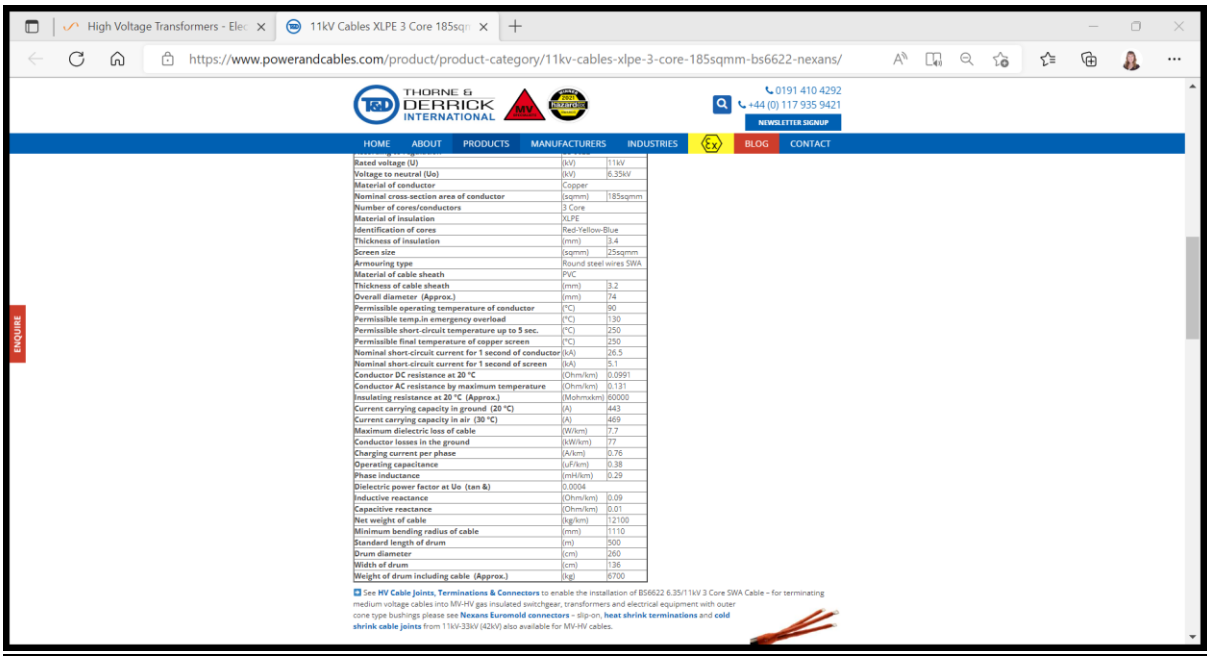
Embodied carbon for copper in transformers is 20 units 85,000 Kg x 13.8% x 0.84 KgCO2e/Kg =

197,064 Kg

Total = 421,073 + 197,064 = 618,137 Kg

Cables

According to [redacted]/ (see following screenshot), weight of 11kV cable drum is 6.7 tonnes and 500m in length of copper cable.



Rated voltage (U)	(kV)	11kV
Voltage to neutral (Uo)	(kV)	6.35kV
Material of conductor	Copper	
Nominal cross-section area of conductor	(sqmm)	185sqmm
Number of cores/conductors	3 Core	
Material of insulation	XLPE	
Identification of cores	Red-Yellow-Blue	
Thickness of insulation	(mm)	3.4
Screen size	(sqmm)	25sqmm
Armouring type	Round steel wires SWA	
Material of cable sheath	PVC	
Thickness of cable sheath	(mm)	3.2
Overall diameter (Approx.)	(mm)	74
Permissible operating temperature of conductor	(°C)	90
Permissible temp.in emergency overload	(°C)	130
Permissible short-circuit temperature up to 5 sec.	(°C)	250
Permissible final temperature of copper screen	(°C)	250
Nominal short-circuit current for 1 second of conductor	(kA)	26.5
Nominal short-circuit current for 1 second of screen	(kA)	5.1
Conductor DC resistance at 20 °C	(Ohm/km)	0.0991
Conductor AC resistance by maximum temperature	(Ohm/km)	0.131
Insulating resistance at 20 °C (Approx.)	(Mohmxkm)	60000
Current carrying capacity in ground (20 °C)	(A)	443
Current carrying capacity in air (30 °C)	(A)	469
Maximum dielectric loss of cable	(W/km)	7.7
Conductor losses in the ground	(kW/km)	77
Charging current per phase	(A/km)	0.76
Operating capacitance	(uF/km)	0.38
Phase inductance	(mH/km)	0.29
Dielectric power factor at Uo (tan &)	0.0004	
Inductive reactance	(Ohm/km)	0.09
Capacitive reactance	(Ohm/km)	0.01
Net weight of cable	(kg/km)	12100
Minimum bending radius of cable	(mm)	1110
Standard length of drum	(m)	500
Drum diameter	(cm)	260
Width of drum	(cm)	136
Weight of drum including cable (Approx.)	(kg)	6700

See HV Cable Joints, Terminations & Connectors to enable the installation of BS6622 6.35/11kV 3 Core SWA Cable – for terminating medium voltage cables into MV-HV gas insulated switchgear, transformers and electrical equipment with outer cone type bushings please see Nexans Euromold connectors – slip-on, heat shrink terminations and cold shrink cable joints from 11kV-33kV (42kV) also available for MV-HV cables.

Copper has an embodied carbon value of 0.8 KgCO2e/Kg **[11, also Ref 6-4 in Sunnica ES].** We have a 24 km run of cable therefore we need 48 drums, such that:

Embodied carbon for copper cabling is 48 drums x 6,700 Kg per drum x 0.8 KgCO2e/Kg = 257,000 KgCO2e

Appendix G: Worked calculations for construction and operational emissions

(Example given for 500MW field, a similar calculation applies to a 625MW field)

G1: Table 3 workings-out for calculating "product" emissions in the Construction phase

NB: These calculations use the given embodied benchmarks and emissions intensities given in ES Section 6.3.18 Table 6.1 p6-5 (Table 3 in the report)

PV modules:

13,638,085 MWh x 0.0103 KgCO2e/kWh = **140,472 tCO2e** (13,638,085 kWh is energy output at year 30, expected lifetime of PV panel)

PV Inverters:

210 kWh/KW x 0.295 kgCO2e/kWh x 500,000 MW field = **30,975 tCO2e**

BESS Inverters:

210 kWh/kW x 0.57 kgCO2e/kWh x 500,000 MW Field = **59,850 tCO2e**

Switchgear:

175 kgCO2e/KV x 500,000 MW field = **87,500 tCO2e** (KV to KW not quite comparable but close enough)

Li-ion batteries (BESS):

Lower end of battery range: 500,000 KWh x155 kg/kWh = **77,500 tCO2e**
Upper end of battery range: 1511,000 kWh x 155 kg/kWh = **234,205 tCO2e**

Range of 500 to 1511MWh assumed for batteries, given that no hard data available on this in Sunnica documentation (both ends of storage capacity range are "mentioned" in Sunnica communications)

Module structures:
these have not been included by Sunnica and therefore, in attempting to replicate their methodology for estimating emissions have not been included by Cranfield.

Transformers:

The 697 tCO2e for transformer emissions comes from an assumed **20 Units of 50MVA** transformers (see ampcontrolgroup.com for transformer spec). Each transformer is 52.7% steel and 13.8% copper. Recycled metals (Copper & Steel) assumed (see Appendix F)

Results in **697 tCO2e**

Cables:

The 257 tCO2e comes from the assumption that 11kV lines are used [redacted] **– Recycled Copper is assumed**

Results in **257 tCO2e**

Total "products" emissions: 397,251 to 553,956 tCO2e

Including rest of Table 9-related construction emissions, total constructions emissions for 500 MW field = 429,548 to 586,253 tCO2e

G2: Table 6 workings-out for calculating emissions in the operation phase (over 40 years)

PV Modules:

140,472 tCO2e x 0.2% (given replacement rate) x 40 years = **11,237.76 tCO2e**

PV Inverters:

30,975 tCO2e x 4.4% (given replacement rate) x 40 years = **54,516 tCO2e**

BESS Inverters:

59,850 tCO2e x 3.1% (given replacement rate) x 40 years = **74,214 tCO2e**

Switchgears:

87,500 tCO2e x 0.8% (given replacement rate) x 40 years = **28,000 tCO2e**

Batteries/BESS:

Assuming a 13-year lifetime, there will be original installation during Construction plus 2 replacements during 40 year lifespan of Scheme, hence

@500 MWh storage capacity: 77,500 tCO2e x 2 = **155,000 tCO2e**

@1511 MWh storage capacity: 234,205 tCO2e x 2 = **468,410 tCO2e**

Module Structures:

Not included in construction estimations (as per Sunnica's methodology, therefore not included here in operations either)

Transformers:

697 tCO2e x 1.8% (given replacement rate) x 40 years = **13 tCO2e**

Appendix H: Spreadsheet for calculation of cumulative GHG emissions and GHG offset based on Sunnica's given values:

Year	Annualized Operation GHG (tCO2e)	Cummulative GHG (tCO2e)	Grid Carbon intensity electricity - $gCO2_e$/kWh	Plant's Energy Ouput (MWh)	GHG Offset (tCO2e)	Cummulative GHG Offset (tCO2e)	Total GHG (tCO2e)
0	452,015.00	452,015.00			0	0	676,009.00
1	5,220.23	457,235.23	108	643,361.00	63,812.03	63,812.03	676,009.00
2	5,220.23	462,455.45	90	639,822.51	51,920.13	115,732.16	676,009.00
3	5,220.23	467,675.68	85	636,303.49	48,628.35	164,360.52	676,009.00
4	5,220.23	472,895.90	91	632,803.82	52,039.20	216,399.71	676,009.00
5	5,220.23	478,116.13	98	629,323.40	56,234.48	272,634.19	676,009.00
6	5,220.23	483,336.35	89	625,862.12	50,328.04	322,962.23	676,009.00
7	5,220.23	488,556.58	83	622,419.88	45,843.97	368,806.20	676,009.00
8	5,220.23	493,776.80	84	618,996.57	46,181.96	414,988.17	676,009.00
9	5,220.23	498,997.03	85	615,592.09	46,624.37	461,612.53	676,009.00
10	5,220.23	504,217.25	87	612,206.33	47,598.41	509,210.94	676,009.00
11	5,220.23	509,437.48	78	608,839.20	42,173.48	551,384.42	676,009.00
12	5,220.23	514,657.70	71	605,490.58	37,656.45	589,040.87	676,009.00
13	5,220.23	519,877.93	67	602,160.38	35,127.10	624,167.96	676,009.00
14	5,220.23	525,098.15	70	598,848.50	36,416.63	660,584.59	676,009.00
15	5,220.23	530,318.38	69	595,554.84	35,620.74	696,205.32	676,009.00
16	5,220.23	535,538.60	67	592,279.28	34,239.21	730,444.54	676,009.00
17	5,220.23	540,758.83	27	589,021.75	10,592.39	741,036.92	676,009.00
18	5,220.23	545,979.05	27	585,782.13	10,534.13	751,571.05	676,009.00
19	5,220.23	551,199.28	27	582,560.33	10,476.19	762,047.24	676,009.00
20	5,220.23	556,419.50	27	579,356.24	10,418.57	772,465.81	676,009.00
21	5,220.23	561,639.73	27	576,169.79	10,361.27	782,827.08	676,009.00
22	5,220.23	566,859.95	27	573,000.85	10,304.28	793,131.37	676,009.00
23	5,220.23	572,080.17	27	569,849.35	10,247.61	803,378.98	676,009.00
24	5,220.23	577,300.40	27	566,715.18	10,191.25	813,570.22	676,009.00
25	5,220.23	582,520.62	27	563,598.24	10,135.20	823,705.42	676,009.00
26	5,220.23	587,740.85	27	560,498.45	10,079.45	833,784.87	676,009.00
27	5,220.23	592,961.07	27	557,415.71	10,024.01	843,808.88	676,009.00
28	5,220.23	598,181.30	27	554,349.92	9,968.88	853,777.77	676,009.00
29	5,220.23	603,401.52	27	551,301.00	9,914.05	863,691.82	676,009.00
30	5,220.23	608,621.75	27	548,268.84	9,859.53	873,551.35	676,009.00
31	5,220.23	613,841.97	27	545,253.37	9,805.30	883,356.65	676,009.00
32	5,220.23	619,062.20	27	542,254.47	9,751.37	893,108.02	676,009.00
33	5,220.23	624,282.42	27	539,272.07	9,697.74	902,805.75	676,009.00
34	5,220.23	629,502.65	27	536,306.08	9,644.40	912,450.15	676,009.00
35	5,220.23	634,722.87	27	533,356.39	9,591.36	922,041.51	676,009.00
36	5,220.23	639,943.10	27	530,422.93	9,538.60	931,580.11	676,009.00
37	5,220.23	645,163.32	27	527,505.61	9,486.14	941,066.25	676,009.00
38	5,220.23	650,383.55	27	524,604.33	9,433.97	950,500.22	676,009.00
39	5,220.23	655,603.77	27	521,719.00	9,382.08	959,882.30	676,009.00
40	20,405.23	676,009.00	27	518,849.55	9,330.48	969,212.78	676,009.00
				23,157,295.58	**969,212.78**		

For Sunnica's unknown field size and unknown battery storage capacity, the given figures are:

Operational output in year 1: 643,361 MWh (given)

Total Constructions Emissions: 452,015 tCO2e (given)

Total Operation Emissions: 208,809 tCO2e (given)

Total Decommissioning Emissions: 15,185 tCO2e (given)

Operational Scheme GHG Intensity: 9.02 gCO2e/kWh (given based on Operational emissions of 208,809 tCO2e and total energy generation (23 TWh)

Column 1: gives the year

Column 2: In year 0 (construction years) the emissions will thus be 452,015 tCO2e, thereafter each year, operational emissions will be 5,220.23 tCO2e (or 208,809 tCO2e divided by 40 years). (Decommissioning is included in year 40 i.e. 5,220.23 + 15,185 = 20,405.23 tCO2e).

Column 3: The cumulative emissions are shown in column 3.

Column 4: The grid carbon intensity is given in column 4.

Column 5: The plant's output energy in year 1 is 643,361 MWh (given) with a degradation rate of 0.55% for the PV modules each year.

Column 6: GHG offset is given in column 6. It is calculated thus:

GHG offset = Grid CO2 from electricity generated – CO2 Emissions from Scheme

GHG Offset $= Energy\ output\ (KWh) \times Operational\ Grid\ Intensity\ \left(\frac{gCO2e}{KWh}\right)$

$- Energy\ output\ (KWh) \times Operational\ Scheme\ Intensity\ (\frac{gCO2e}{KWh})$

Therefore $GHG\ Offset\ = Energy\ output\ (KWh) \times (Grid\ Intensity - Scheme\ Intensity)(\frac{gCO2e}{KWh})$

Using year 1, as an example:

GHG Offset = [643,361 x (108.20 – 9.02)]/1000 ≈ 63,812.03 tCO2e (excluding rounding errors)

Column 7: Cumulative GHG Offset is given in Column 7

Column 8: Total GHG is final cumulative GHG at year 40 (see Column 3)

In a likewise manner individual spreadsheets and plots can be produced for different scenarios: for 500MW and 625 MW field sizes and battery storage capacity ranges of 500 MWh to 1511 MWh

Appendix I: Spreadsheet for calculation of cumulative GHG emissions and GHG offset for a 500 MWp field using 500 MWh battery storage

Year	Annualized Operation GHG (tCO2e)	Cummulative GHG (tCO2e)	Grid Carbon intensity electricity - $gCO2_e$/kWh	Plant's Energy Ouput (MWh)	GHG Offset (tCO2e)	Cummulative GHG Offset (tCO2e)	Total GHG (tCO2e)
0	429,548.00	429,548.00			0	0	807,386.00
1	9,066.33	438,614.33	108	491,890.00	43,148.38	43,148.38	807,386.00
2	9,066.33	447,680.65	90	489,184.61	34,087.29	77,235.67	807,386.00
3	9,066.33	456,746.98	85	486,494.09	31,601.37	108,837.04	807,386.00
4	9,066.33	465,813.30	91	483,818.37	34,239.85	143,076.89	807,386.00
5	9,066.33	474,879.63	98	481,157.37	37,477.92	180,554.81	807,386.00
6	9,066.33	483,945.95	89	478,511.01	32,992.42	213,547.23	807,386.00
7	9,066.33	493,012.28	83	475,879.20	29,594.24	243,141.47	807,386.00
8	9,066.33	502,078.60	84	473,261.86	29,882.67	273,024.13	807,386.00
9	9,066.33	511,144.93	85	470,658.92	30,250.76	303,274.89	807,386.00
10	9,066.33	520,211.25	87	468,070.30	31,025.16	334,300.05	807,386.00
11	9,066.33	529,277.58	78	465,495.91	26,906.97	361,207.02	807,386.00
12	9,066.33	538,343.90	71	462,935.68	23,482.77	384,689.79	807,386.00
13	9,066.33	547,410.23	67	460,389.53	21,578.12	406,267.91	807,386.00
14	9,066.33	556,476.55	70	457,857.39	22,593.08	428,860.99	807,386.00
15	9,066.33	565,542.88	69	455,339.18	22,013.44	450,874.43	807,386.00
16	9,066.33	574,609.20	67	452,834.81	20,985.90	471,860.33	807,386.00
17	9,066.33	583,675.53	27	450,344.22	2,934.97	474,795.29	807,386.00
18	9,066.33	592,741.85	27	447,867.33	2,918.82	477,714.11	807,386.00
19	9,066.33	601,808.18	27	445,404.06	2,902.77	480,616.88	807,386.00
20	9,066.33	610,874.50	27	442,954.33	2,886.80	483,503.69	807,386.00
21	9,066.33	619,940.83	27	440,518.09	2,870.93	486,374.62	807,386.00
22	9,066.33	629,007.15	27	438,095.24	2,855.14	489,229.75	807,386.00
23	9,066.33	638,073.48	27	435,685.71	2,839.43	492,069.19	807,386.00
24	9,066.33	647,139.80	27	433,289.44	2,823.82	494,893.00	807,386.00
25	9,066.33	656,206.12	27	430,906.35	2,808.29	497,701.29	807,386.00
26	9,066.33	665,272.45	27	428,536.36	2,792.84	500,494.13	807,386.00
27	9,066.33	674,338.77	27	426,179.41	2,777.48	503,271.61	807,386.00
28	9,066.33	683,405.10	27	423,835.43	2,762.20	506,033.81	807,386.00
29	9,066.33	692,471.42	27	421,504.33	2,747.01	508,780.82	807,386.00
30	9,066.33	701,537.75	27	419,186.06	2,731.90	511,512.72	807,386.00
31	9,066.33	710,604.07	27	416,880.53	2,716.88	514,229.60	807,386.00
32	9,066.33	719,670.40	27	414,587.69	2,701.93	516,931.54	807,386.00
33	9,066.33	728,736.72	27	412,307.46	2,687.07	519,618.61	807,386.00
34	9,066.33	737,803.05	27	410,039.77	2,672.29	522,290.90	807,386.00
35	9,066.33	746,869.37	27	407,784.55	2,657.60	524,948.50	807,386.00
36	9,066.33	755,935.70	27	405,541.73	2,642.98	527,591.48	807,386.00
37	9,066.33	765,002.02	27	403,311.26	2,628.44	530,219.93	807,386.00
38	9,066.33	774,068.35	27	401,093.04	2,613.99	532,833.91	807,386.00
39	9,066.33	783,134.67	27	398,887.03	2,599.61	535,433.52	807,386.00
40	24,251.33	807,386.00	27	396,693.15	2,585.31	538,018.84	807,386.00
				17,705,210.79	**538,018.84**		

For our estimation for a 500 MW field and 500 MWh battery storage capacity:

Total Constructions Emissions: 429,548 tCO2e

Total Operation Emissions: 362,653 tCO2e

Total Decommissioning Emissions: 15,185 tCO2e (given)

Our estimated energy output is 491,890 MWh in year 1

Grid operational intensity alters yearly until it levels at 27 gCO2e/KWh

Our operational Scheme Intensity is estimated at 21 gCO2e/KWh

Appendix J: Matrix for calculations of GHG emissions for different field sizes, different battery storage capacities and different battery replacement rates.

Construction GHG (tCO2e)

	500MW Field			625MW Field		
Battery Replacement	500MWh BESS Capacity	1026MWh BESS Capacity	1511MWh Capacity	500MWh BESS Capacity	1026MWh BESS Capacity	1511MWh Capacity
0%	429,548.00	511,078.00	586,253.00	517,863.00	599,393.00	674,568.00
100%	429,548.00	511,078.00	586,253.00	517,863.00	599,393.00	674,568.00
200%	429,548.00	511,078.00	586,253.00	517,863.00	599,393.00	674,568.00

Operation (tCO2e)

	500MW Field			625MW Field		
Battery Replacement	500MWh BESS Capacity	1026MWh BESS Capacity	1511MWh Capacity	500MWh BESS Capacity	1026MWh BESS Capacity	1511MWh Capacity
0%	207,653.00	207,653.00	207,653.00	250,299.00	250,299.00	250,299.00
100%	285,153.00	366,683.00	441,858.00	327,799.00	409,329.00	484,504.00
200%	362,653.00	525,713.00	676,063.00	405,299.00	568,359.00	718,709.00

Decommissioning (tCO2e)

	500MW Field			625MW Field		
Battery Replacement	500MWh BESS Capacity	1026MWh BESS Capacity	1511MWh Capacity	500MWh BESS Capacity	1026MWh BESS Capacity	1511MWh Capacity
0%	15,185.00	15,185.00	15,185.00	15,185.00	15,185.00	15,185.00
100%	15,185.00	15,185.00	15,185.00	15,185.00	15,185.00	15,185.00
200%	15,185.00	15,185.00	15,185.00	15,185.00	15,185.00	15,185.00

Total GHG Emissions (tCO2e)

	500MW Field			625MW Field		
Battery Replacement	500MWh BESS Capacity	1026MWh BESS Capacity		500MWh BESS Capacity	1026MWh BESS Capacity	
0%	652,386.00	733,916.00	809,091.00	783,347.00	864,877.00	940,052.00
100%	729,886.00	892,946.00	1,043,296.00	860,847.00	1,023,907.00	1,174,257.00
200%	807,386.00	1,051,976.00	1,277,501.00	938,347.00	1,182,937.00	1,408,462.00

Using the 500 MW field as an example:

- Construction emissions are calculated as per Appendix G.
- Operation emissions are calculated as explained using methodology:
    - in Table 6 to calculate “maintenance” emissions.
    - and adding Table 5 items such as worker transportation and operation.
- Decommisioning emissions are based on Sunnica’s presented values.

Both construction and operation emissions will vary according to the battery storage capacity size used (500, 1026 or 1511 MWh, here representing “low”, “medium” and “high” values of our assumed storage capacity range).