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Steeple Renewables Project

Note on Scheme Efficiency

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1. Introduction

1.1 Purpose of this document

1.1.1 This document gives an overview of the Scheme output including how factors like PV panel technology and grid utilisation influence scheme design and inform land use efficiency i.e. the justification for why the amount of land in the scheme is required to produce the energy to be generated by the Scheme.

1.2 Glossary

1.2.1 To help understanding the different technical vocabulary included in this document a glossary is provided below:

- AC (Alternative Current): A type of electrical current, the direction of which is reversed at regular intervals or cycles.
- Active Power: The product of voltage and the in-phase component of alternating current measured in units of megawatts (MW)
- Apparent power: The product of voltage and current at fundamental frequency, and the square root of three (in the case of three phase systems) expressed in megavolt-amperes (MVA).
- BESS (Battery Energy Storage System): A BESS is a system that uses batteries to store electrical energy.
- Capacity Factor: The ratio of the electrical energy produced by a generating unit for a given period of time to the electrical energy that could have been produced at continuous full power operation during the same period. In this document we assume the period of time to be a year.
- DC/AC Ratio: The ratio between the installed capacity of the DC part (calculated from the number and capacity of the PV modules) to the installed capacity of the AC part of the inverters
- DC capacity: the aggregate rated power output of the PV modules forming part of the Solar Power Plant expressed in MWp or MWDC
- GCR (Ground Covering Ratio): The GCR is defined as the total module area divided by the total ground area occupied by the array.
- Inverter capacity: Inverter power output usually measured in megawatts (MWAC).

- Inverter Clipping: Inverter saturation, commonly referred to as "clipping", occurs when the DC power from the PV array exceeds the maximum input level for the inverter. In response to this condition, the inverter typically adjusts DC voltage to reduce the DC power.
- MEC (Maximum Export Capacity) : The MEC represents the maximum power that can be exported to the grid expressed in MWAC
- MWAC (Mega Watt Alternating Current): One million Watts of alternating current. When associated with "inverter", it represents the power or capacity of the PV plant inverters (the aggregation of all inverters rated capacities). When associated with MEC it represents he maximum power that can be exported to the grid.
- MWDC (Mega Watt Direct Current) or MWp (Mega Watt peak): Output of a solar array, which when operating at its peak power point under Standard Test Conditions produces one million watts direct current.
- MWh (Mega Watt Hour): Energy produced by a PV plant delivering one MW for one hour (rated in terms of AC).
- MWh/MWp: Number of MWh produced per annum by the PV plant per for each MWP of installed DC Capacity. Called also specific production.
- Ntype TopCon (Tunnel Oxide Passivated Contact): Type of PV modules manufactured with high-performance solar cells that use innovative technology to increase efficiency and power output. The N-type ToPCon technology uses a thin layer of insulating material, called a tunnel oxide layer, to passivate the contacts on the front and back sides of the solar cell, which reduces recombination losses and increases power output.
- Pitch distance: Distance from the axis of one racking system to the next.
- PV module: Main component of an energy conversion system that uses the semiconductor technology to convert sunlight energy into electrical power
- PV Array: Multiple solar panels electrically wired together to form a much larger PV installation (PV system) called an array.
- SAT (Single Axis Tracker): Type of racking system used in a PV installation that allows the movement of the PV modules in one direction, from east to west, following the sun's path from sunrise to sunset.

- PV Inverter: Device within a photovoltaic (PV) system that converts the direct current (DC) electricity generated by solar panels into usable alternating current (AC) electricity
- STC = Standard Test Conditions: For PV module testing, defined in international standards; insolation intensity of 1000W/m2 normal to the plane of the PV module at ambient temperature of 25°C and light spectrum equivalent to AM1.5.
- kV (kilo Volt): A unit of potential equal to a thousand volts. In this document represents the voltage of the grid connection solution.
- Wp (Watt peak): maximum power output a solar panel can produce under STC.

1.3 Main design parameters

1.3.1 The Scheme's grid connection agreement has a 600MW export AC capacity (Maximum Export Capacity or MEC). This capacity is anticipated to be shared between the Solar Project and the BESS, respectively 450 MWAC and 150 MWAC.

1.3.2 The scheme will connect at 400kV to the NGET transmission network at West Burton 400kV Substation from the project substation via approx. 700m of 400kV underground cable.

1.3.3 The indicative installed capacity of the Scheme will be around 548MWp DC assuming 655Wp solar modules (this installed capacity represents the total number of PV modules installed in the buildable area multiplied by the power output of each PV module). This number of modules and power output is necessarily indicative as module and cell technologies continue to evolve quite quickly. The ratio of the installed DC capacity to the AC MEC is not equal to 1 due to two main factors:

- the output power of a module is defined at specific Standard Test Conditions (STC) which are very different from the real outdoor conditions and therefore a 655Wp PV module during its operational life will deliver much less output power. Radiance levels vary throughout the day and year and are weather dependant, which directly affect power production, as does temperature, to a lesser extent

1.3.4 The graph below which presents the typical power produced (for the 1st year with no degradation applied) by 1 PV module of 655Wp, demonstrates this:

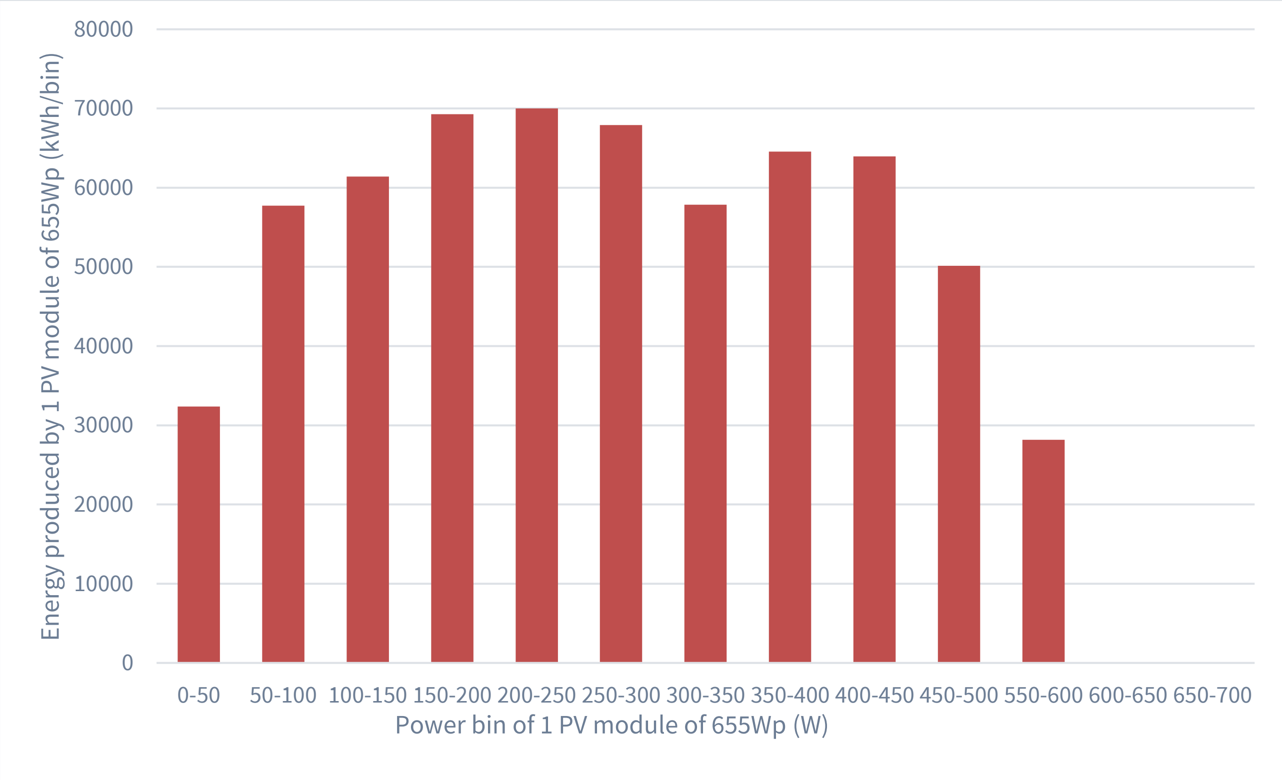


Figure 1- Typical 1st year power production of 1 PV module of 655Wp

- the second factor is that the performance of PV modules reduces during their lifetime, as process called module degradation. Generally, for the proposed type of cell/module technology this degradation rate is assumed to be 0.5%per annum). This means the total installed DC capacity of 548 MWp will progressively decrease over time. More details about PV module degradation are given in section 3.

1.3.5 Taking into account these two mechanisms in maximising the energy injected into the grid and making efficient use of the available grid capacity, the installed DC capacity of the Scheme will inevitably be higher than the MEC.

1.3.6 `Also taking into account the buildable area available and the density of the PV modules installed (see 5.1.3) the Scheme achieves an indicative DC/AC ratio of 1.22.

1.3.7 This ratio is in the range of standard values used in the PV industry and represents a good balance between the amount of land used and levels of use of grid capacity/energy production achieved.

1.3.8 The Scheme uses inverters to convert the DC generated by the PV modules into ac. For few hours during a year (estimated at 36 hours per annum or 0.41% of the total available generating hours per annum) when irradiance levels are high and module temperature is low, the DC capacity delivered by the modules could be higher than the MEC limit and in that case the inverters will derate to prevent any exceedance of energy injection into the grid (this mechanism is called inverter clipping). During these episodes no electrical losses occur as excess power is simply not produced (the inverter reduces its output in order to not exceed the MEC value).

1.4 PV Module Degradation

1.4.1 Aging is the main degradation mechanism affecting PV modules throughout their years of operation. This degradation mechanism is a direct consequence of modules being exposed for years to rainfall, snowfall, extreme temperatures, hail, dust, and other external forces.

1.4.2 PV Module manufacturing processes, technologies, raw materials and outdoor conditions all effect this mechanism with most PV module suppliers providing a guaranteed power performance for 25/30 years.

1.4.3 As stated above, for mainstream cell/module technologies, this degradation value is typically around 0.5% per annum of operation for a well-maintained PV plant.

1.4.4 For this scheme and the PV module technology anticipated to be used: dual glass Ntype TopCon, the power degradation guarantee from the supplier is 1% for the 1st year of operation and then 0.4% each year for the next 29 years (30 years guarantee in total). After 30 years there is no continuing guarantee from the supplier and so difficult to predict if the 0.4%/y degradation rate will still be applicable or if the aging will accelerate.

1.4.5 RES typically adopts a conservative approach any assumes the typical value discussed in 3.1.1; 0.5% per annum for 40 years of operation.

1.4.6 By applying this rate to the initial installed DC capacity of 548MWp, the expected equivalent MWp generation after 40 years is 448.5MWp which is marginally below the 450MW MEC capacity of the Scheme.

1.4.7 The following graph illustrates the effect of the module degradation on the DC installed capacity:

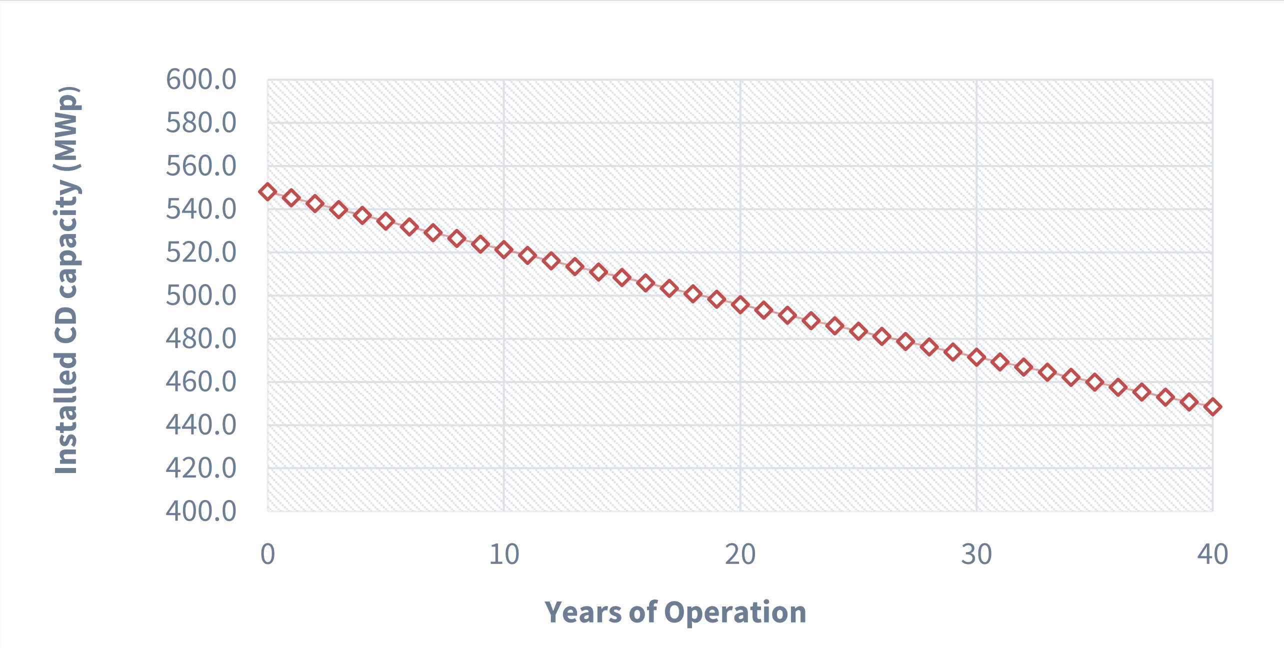


Figure 2- Effect of the module degradation on the DC installed capacity

1.4.8 As discussed in 2.1.2 there are generally 2 main reasons why the DC installed capacity of a PV solar farm is oversized (also called overplanting) relative to its AC Maximum Export Capacity; the difference between STC and real outdoor conditions and the ageing of the modules.

1.4.9 As explained in 3.1.2 above the module degradation provision illustrates the reason for overplanting as after 40 years of operation, the expected equivalent MWp generation will at that point be just beneath the AC MEC value.

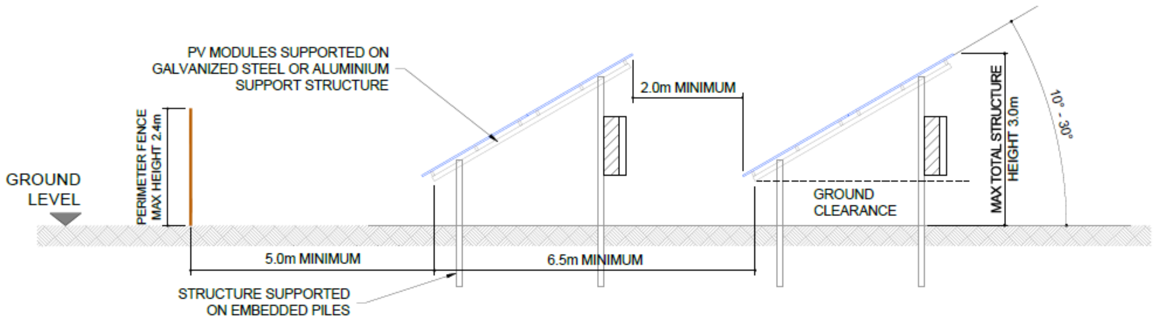
1.5 Panel Configuration

1.5.1 The Scheme has used industry leading software in the design of the PV plant and to calculate the expected energy generation over its lifetime.

1.5.2 The PV modules will be displayed on south facing fix tilted racking structures, up to 3m above ground. These arrays are static, being placed at the optimum fixed angle to make best use of the site irradiance over the course of the year.

1.5.3 The tilt angle is nominally set at 20deg but might vary in the range of 10 to 26deg.

1.5.4 To limit their visual appearance the maximum height of the structures has been limited to 3m.



1.5.5 In order to maximise the usage of the buildable area, the racking structures' pitch distance (distance from a row to the next one) for this Scheme has been set at 7.62m. This value strikes a good balance between maximising land usage and minimising the land consumption and between maximising the energy output and the use of the grid capacity without compromising operability by maintaining sufficient space between the different rows of racking system to allow the maintenance of the PV plant during operation.

1.5.6 The pitch drives the Ground Covering Ratio (GCR) which represents the ratio of the total project buildable area by the total PV module area.

1.5.7 With a 7.62m pitch distance, the GCR for this Scheme is 0.65. This means that 65% of the total buildable area is covered by PV modules. The 35% remaining is the rest of the PV plant infrastructure (tracks, inverters, transformers, substation) and the space left between the rows and the space between the fence and the rows.

1.5.8 The total surface area fenced for this Scheme is 1200 acres.

1.5.9 The illustrative design includes 836,808 panels, giving an installed capacity of 548MWp DC with a yield of 529,991 MWh per year. This is a load factor of about 11.04% which again is typical for similar schemes in UK locations at this latitude.

1.6 Land Use Efficiency

1.6.1 The land use efficiency of the Scheme is illustrated by the 2.7 acres/MW achieved (1200 acres / 450 MWAC)

1.6.2 This ratio is well in line with the EN-3 paragraph 2.10.17 figure of 2 – 4 acres per MW for large scale solar and reflects the 0.65 GCR described in 5.1.3.

1.6.3 An alternative would involve the use of Single Axis Tracker (SAT) which mounts the panel arrays on platforms with limited amount of capability to track the movement of the sun during the day. Whilst doing so would increase the energy production of each individual panel (by an average 10/12% compared to a south facing fix tilt) this design cannot achieve similar levels of GCR (SAT will have GCR in a range between 0.3 to 0.4) as the tables are oriented North/South and tracking is East to West. With such a design, as GCR increases the benefits of the tracking decrease.

1.6.4 The comparative differences between the designs can be illustrated by these figures:

- SAT on this site would operate at 45% less installed capacity, but
- SAT would overall produce 36% less total energy than FSF.

1.6.5 Policy in EN-3 does not favour one design approach over another, with examples of both being pursued in recent DCO applications.