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CARBON FOOTPRINT ASSESSMENT OF TWO PHOTOVOLTAIC PLANTS

Abstract

As the world moves towards sustainable energy sources to reduce the impacts of climate change, photovoltaic (PV) systems have become a crucial player in the renewable energy sector. This study evaluates the carbon footprint linked with the life cycle of PV plants. The aim is to give valuable insights into the environmental effects of their deployment.

This article analyzes and compares the greenhouse gas emissions of two solar photovoltaic plants in Portugal. Both plants have the same equipment, peak power, and nominal power for injection into the grid. The only difference between them is the metal structure that supports the photovoltaic modules: plant A has a 2V tracker-type structure, and plant B has a 2V fixed structure. By comparing the two, it will be possible to determine the effect of the different structures on greenhouse gas emissions and the total energy output over the plant's 30-year lifespan.

Key-words: Photovoltaic Plant; Life Cycle Analysis; Green House Gases; Carbon footprint

1. Introduction

As per the European Green Deal [1], reducing carbon emissions from the European energy system is essential to achieve climate goals by 2030 and 2050. Photovoltaics (PV) are expected to play a significant role in this process. Hence, it is crucial to ensure that newly installed PV modules are cost-effective and competitive while being environmentally friendly [2].

As the world works harder to reduce carbon emissions, examining the environmental impact of renewable energy solutions is essential. The carbon footprint of PV plants should be assessed throughout their entire lifecycle, including manufacturing, installation, operation, and decommissioning [3].

The number of PV solar plants and their rated capacity are increasing daily. PV technology harnesses sunlight to produce electricity, a clean and renewable alternative to traditional power generation that relies on fossil fuels. It's impossible to compare the carbon footprint (CF) between other fossil energy sources and PV solar energy. Figure 1 compares PV plants with other energy sources [4], confirming that photovoltaic solar energy can reduce greenhouse gas (GHG) emissions and positively impact the planet.

Although clean and renewable energy sources like photovoltaic (PV) plants are environmentally friendly, the mining, manufacturing, and transportation of the products and equipment involved in building them are only sometimes as clean. As we followed a PV plant's development and procurement phase, we saw many diesel-powered machines, hundreds of trucks loaded with containers from all over the world, and various materials needed to harness the energy the sun provides daily.

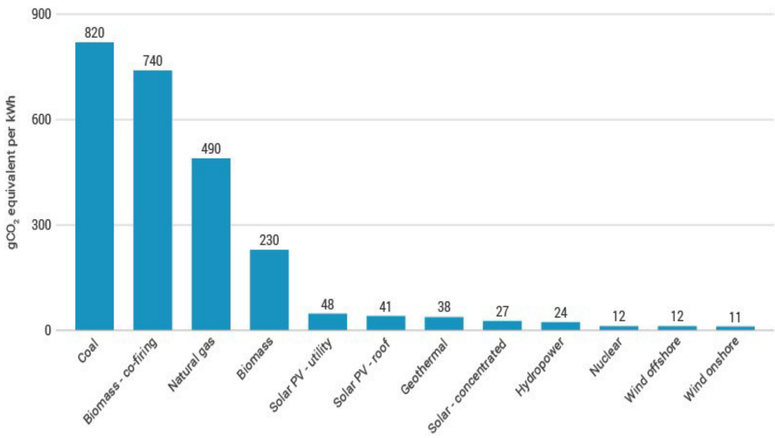

Figure 1 - GHG emissions of different energy sources

The evaluation covers the complete life cycle of photovoltaic (PV) plants, from extracting raw materials to manufacturing, transportation, installation, operation, and decommissioning. Life cycle assessment (LCA) techniques, including carbon footprint calculations, measure greenhouse gas emissions throughout the lifespan of the PV system [5]. The environmental performance of PV electricity generation is influenced by the carbon intensity of PV manufacturing processes and the impact of local grid emissions [6]. Therefore, we place particular emphasis on these factors, namely, the carbon footprint (CF).

Portugal benefits from one of the highest levels of solar radiation in Europe, which leads to better CF results when compared to other countries, as shown in Figure 2 [7]. This high solar radiation significantly impacts the performance of PV plants, allowing them to produce more energy and thereby reducing greenhouse gas emissions.

Photovoltaic trackers are structures designed to follow the sun's path across the sky, optimizing the orientation of solar panels to maximize energy capture. While PV trackers can enhance energy yield, they also introduce additional costs.

In this article, we will conduct a Life Cycle Analysis of two photovoltaic (PV) plants: a tracker PV Plant A and a fixed PV Plant B. These plants have a capacity of 11,86 MWp and a nominal power with injection into the grid of 10 MVA. We aim to calculate their environmental impact throughout their lifecycle.

2. Life Cycle Analysis Methodology

Life Cycle Analysis (LCA) is a methodical approach used to evaluate the ecological impact of a product or process during its entire life cycle. It helps assess the environmental aspects related to the production, operation, and decommissioning of a PV power plant [8].

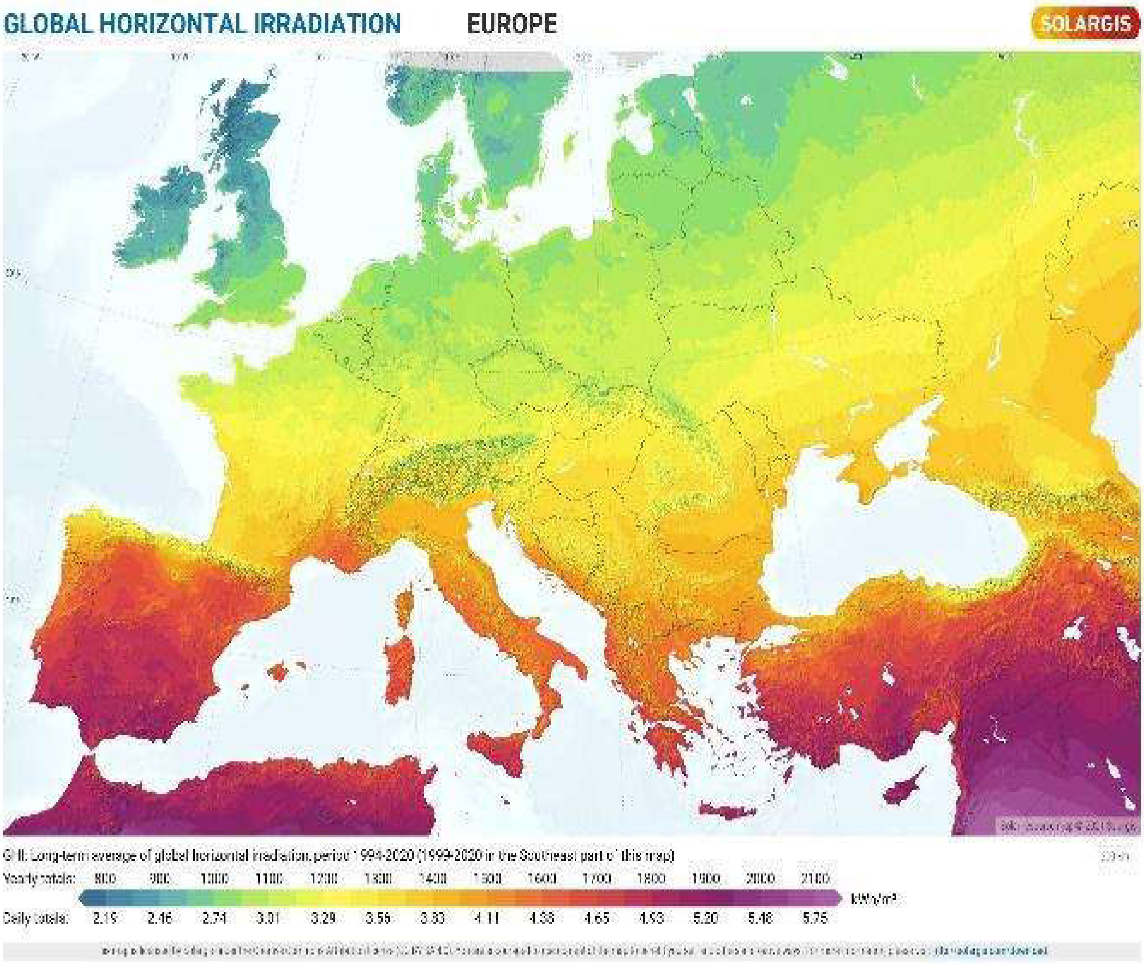

Figure 2 – Solar radiation in Europe

This method involves creating an accounting balance sheet that documents the greenhouse gas emissions of each power plant component throughout every stage of its operational life. The inspiration for this article came primarily from sources that illustrate the use of LCA methods in ground-based photovoltaic power plants, with particular emphasis on the IEA Photovoltaic Power Systems Programme (PVPS) report on Life Cycle Inventories and Life Cycle Assessments of Photovoltaic Systems [9].

The CF of a solar project considers various elements, including the definition of the plant entity. For this reason, the equipment upstream of the substation is not considered. The following values are excluded from the assessment [10]:

- Construction site
  - Personal off-site transport (round trip by car, long-distance travel for site requirements)
  - Auxiliary services consumption
- Operation upstream and downstream of construction, such as prospecting, communication, and travel
- Carbon footprint of the entities (finance, offices, structure)
- Cleaning period of modules and O&M. The O&M team visits the plant monthly (except in emergencies), and cleaning modules that only require deionized water and a machine occur once a year.

Those factors were taken out of the assessment as they correspond to a very low CF and a lack of reference values. However, all these factors would have a residual impact on the total value of the LCA of the PV plants analyzed.

3. Case Study: Quantifying the components weight

3.1 PV Module

This element is the most critical regarding the project's carbon footprint, representing the majority share. Generally, the carbon footprint of a PV module produced in 2023 varies between 300 kg CO_2 eq/kW for some module types manufactured in Europe and 800 kg CO_2eq/kW for PV modules made in China [4]. In this case, the PV module is manufactured in China by a reputable brand in the market, Jinko, and has a value of 450 kg CO_2eq/kW [11].

3.2 Structure

The structure of PV plant A is made of steel and coated with magnelis. It is a 2V single-axis tracker. PV plant B has a fixed structure and is made of the same components as Plant A. According to the ADEME GHG report, Plant A requires approximately 120 kg of steel per kW for every metric ton of material [12]. In comparison, plant B requires about 90 kg of steel per kW due to the different types of structures used in each plant.

Calculations were performed using equations (1) and (2). PV Plant A requires 1424400 kg of steel, while PV Plant B fixed structure requires 1068300 kg.

$$PV\ Plant\ A\!:\ 120\ kg \times 11870\ kW = 1424400\ kg \tag{1}$$

$$PV\ Plant\ B\!:90\ kg \times 11870\ kW = 1068300\ kg \tag{2}$$

According to the International Energy Agency (IEA), the carbon footprint of steel is 1,4 kg CO_2 to 1 kg of steel produced [13] , resulting in:

$$PV\ Plant\ A\!:\ 1424400\ kg\ \times 1{,}4\ kg\ CO2\ /\ kg = 3988320\ kg\ CO2\ eq. \tag{3}$$

$$PV\ Plant\ B\!:\ 1068300\ kg\ \times\ 1{,}4\ kg\ CO2\ /\ kg = 2991240\ kg\ CO2\ eq. \tag{4}$$

With this information, it's possible to calculate the carbon footprint of the structure according to the PVPS method:

$$PV\ Plant\ A\!:\ \frac{3988320\ Kg}{11870\ Kw} = 336\ kg\ CO2eq\ /\ kW \tag{5}$$

$$PV\ Plant\ B\!:\ \frac{1068300\ Kg}{11870\ Kw} = 252\ kg\ CO2eq\ /\ kW \tag{6}$$

3.3 Inverters

We are using Huawei Sun2000-215KTL-H technology in this PV plant. The manufacturer provided a carbon footprint report for this inverter, which states that the total GHG emissions are 27466,73 kg CO_2 eq [14]. The usage period, which is 25264,73 kg CO_2eq, accounts for 91,98% of the entire life cycle GHG emissions. Huawei guarantees a 25-year lifespan for the inverter, equal to the plant's lifespan. Therefore, it takes two years to cover the plant's lifespan, and the total GHG emissions for 30 years are estimated to be 32960 kg CO_2eq.

$$CF\ inverter: \frac{32960\ kg\ CO2}{200\ kW} = 164{,}8\ kg\ CO2eq\ /\ kW \quad (7)$$

3.4 MV cells, transformers and cables

In these photovoltaic plants, three types of cables were used: solar cable, AC cable, and MV cable. It is estimated that was generated a carbon footprint (CF) of 70,1 kg CO_2eq. The value adopted for the MV cells and transformers is 10,9 kg CO_2eq [15].

For the installation and de-installation of the plants, the carbon footprint generated is 4,7 kg CO_2eq/kW. The value for installation and de-installation is the same, as both will take the same amount of time, machines, and workforce. Plant A has 2614 m for the fence, and Plant B has 3258 m. It is estimated to generate a carbon footprint of 14,2 kg CO_2eq/kg.

According to the PVPS guide, a margin of 15% should be used to get extra values from all the small pieces not covered in this analysis [9].

4. Result analysis

We have used PVSyst, the software for simulating the energy output of PV plants. The results are presented in Fig. 3 and 4.

As per the data, PV Plant A produced 587 430 MWh of energy over 30 years, whereas PV Plant B produced 458 640 MWh. The degradation of PV modules was also considered in this study. According to the analysis, the total CO_2 production of PV Plant A is 15 773,22 tons CO_2eq, and PV Plant B is 14637,1 tons CO_2eq. Based on these results, we can conclude that the total carbon footprint of PV Plant A is 26,85 g CO_2eq/kWh, and PV Plant B is 31,91 g CO_2eq/kWh.

Equipment	Value	Unit	Co2 (Kg)	Total	Share
Module	11870	KWp	450	5341500	38,9%
Inverter	10000	KW (AC)	164,8	3296000	24,0%
Structure	11870	KWp	336	3988320	29,1%
Cables	11870	KWp	70,1	832087	6,1%
Transformer	10000	KW (AC)	10,9	109000	0,79%
Fencing	2614	m	14,2	37118,80	0,27%
Installation	11870	KWp	4,71	55907,70	0,41%
Uninstallation	11870	KWp	4,71	55907,70	0,41%

Margin	15%	
Total CO2 produced	15773217,38	Kg CO2eq
Total energy produced (30 years)	587430	MWh
Relative GHG emissions	26,85	g CO2eq/kWh

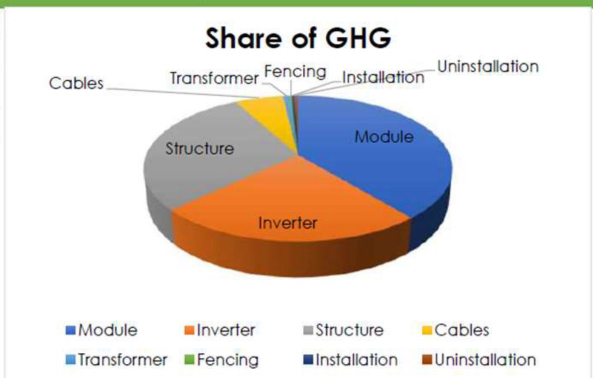

Figure 3 – Calculations sheet of PV plant A

Equipment	Value	Unit	CO2 (Kg)	Total	Share
Module	11870	1 kWp	450	5341500	36,5%
Inverter	10000	1 KVA	164,8	3296000	22,5%
Transformer	10000	1KVA	10,9	109000	0,7%
Structure	11870	KWp	252	2991240	20,4%
Cables	11870	1 kWp	70,1	832087	5,7%
Fencing	3258	m	14,2	46263,6	0,3%
Installation	11870	1 kWp	4,71	55907,7	0,4%
Uninstallation	11870	1 kWp	4,71	55907,7	0,4%

Margin	15%	
Total CO2 produced	14637091,9	Kg CO2eq
Total energy produced (30 years)	458640	MWh
Relative GHG emissions	31,91	g CO2eq/kWh

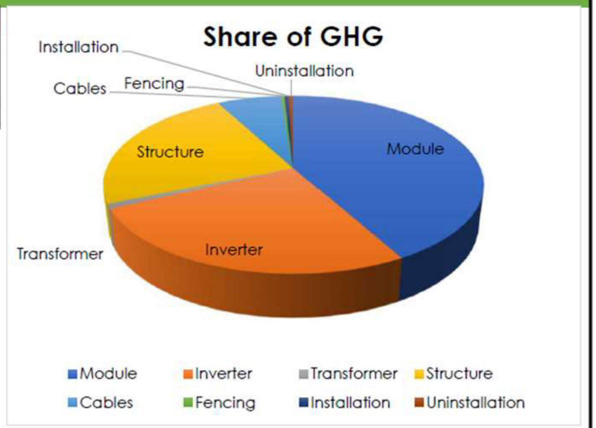

Figure 4 - Calculations sheet of PV plant B

It's worth noting that PV modules significantly impact solar energy production. However, inverters, despite being small equipment, also play a crucial role. This is not only due to the equipment itself but also the utilization phase. It's important to note that the reference was based on the German market, and the values may be significantly increased in Portugal due to the higher solar radiation, as shown earlier in Fig. 2.

When it comes to the structure, using a tracker structure can make a big difference. Even though it has a higher initial Kg CO_2eq than a fixed structure, Plant A is significantly larger than Plant B. This is because the tracker structure can maximize power output from the beginning of the day until the evening, while a fixed structure produces more peak energy only at midday.

As previously mentioned, good results on the CF were expected due to the higher solar radiation in Portugal compared to other PV Plants in Europe.

5. Conclusion

The use of a tracker structure can significantly impact carbon footprint. Government entities may even encourage the use of trackers. Some manufacturers opt for a fixed structure as it is cheaper and requires less workforce. However, while PV trackers can enhance energy efficiency, they also introduce additional costs, primarily associated with the movements involved. The use of trackers offers energy production advantages to manufacturers while also having a lower value of greenhouse gas (GHG) emissions, which government entities prefer. This creates a win-win situation for both parties.

Regarding PV modules, they can have a lower impact. An easy solution could be starting manufacturing in developed countries, reducing emissions by 30% or more. However, the significant barrier is the higher price, which would increase significantly. For instance, an Engineering, Procurement, and Construction (EPC) company stated that buying PV modules at a cost of 0,09€/W would be impossible to compete with if the same modules were produced in a developed country.

Therefore, measures and support from government entities would have to be implemented to ensure that solar PV modules are manufactured in developed countries that care for greenhouse gas emissions. This would bring environmental benefits, create more jobs, and improve the circular economy. With this analysis, we can conclude that photovoltaic solar energy can and should continue to be a strong bet for the desired energy transition. Compared to other sources of electrical energy from fossil sources, PV solar energy is well worth the investment.

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