Assessment of carbon payback time of photovoltaic system considering the Brazilian solar irradiance variation

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Introduction

Photovoltaic (PV) systems along with distributed generation have been identified as one of the solutions to the world's energy and environmental problems because it is a technology with a low carbon footprint [1,2]. In recent years Brazil's electricity regulator ANEEL began to incentivize photovoltaic (PV) adoption through a normative resolution that allowed electricity distribution generation. In addition, ANEEL set a net metering system according to which a consumer's production surplus can be used to offset its consumption in the period or up to 60 months [3]. Those policies served their purpose and heightened the Brazilian solar PV market reaching 2.87 GW of installed capacity in 2020, a growth of more than 600000% since 2012 [4]. Although, little is known about the environmental performance of Distributed generation PV systems when employed under Brazil's solar resource. This research investigates the association between solar irradiation variation across the Brazilian territory and grid-connected photovoltaic (PV) plant's Carbon Payback Time.

Methodology

This study applies a four-step methodology to evaluate a PV plant carbon payback time: define the technological arrangement; calculate the equivalent carbon dioxide emissions quantity during all the life cycle of the power plant, considering the manufacturing origin of the equipment; estimate the electricity production; determine the carbon payback time by comparing the annual equivalent CO_2 emissions of the PV plant with the Brazilian grid to determine the amount of CO_2 emission avoided throughout its lifetime.

Furthermore, the following system boundary and data source were adopted in this study:

- The PV array has a 1 MWp nominal power, rooftop mounting system and grid-connected;
- Polycrystalline (poly-Si) technology panels (weight of 22.0 kg, area of 1.94 m^2, a maximum power rating of 345 Wp, an efficiency of 17.7%, degradation of 0.8% and a lifetime of 25 years) [5];
- The panels, inverter, cables, and mount systems were produced in China;
- The energy required to manufacture them is respectively 2969.0 MJ.m^{-2}, 12.5 MJ.m^{-2}, 125.0 MJ.m^{-2} and 464.7 MJ.m^{-2} [6–8];
- The equipment was transported by vessel (0,0179 kg CO_2.mn^{-1}.ton^{-1}) to Brazil and by trucks (0,051 kg CO_2.km^{-1}.ton^{-1}) for domestic transport [9–11];
- Annual average irradiation from 1,277.50 to 2,281.25 kWh.m^{-2}.year^{-1} [12];
- China and Brazil's electricity grid have the following carbon intensity coefficient respectively 0.821 Kg CO_2.KWh^{-1} and 0.205 Kg CO_2.KWh^{-1} [13,14].

Results

The outcome achieved considering the methodology, boundary conditions and data source presented in the previous section reveals that a typical 1-MW on-grid rooftop-mounted poly-Si station in Brazil is capable to produce free carbon electricity for at least 10.5 years. This is because, the carbon payback time for the Brazilian territory range between 6.5 years to 14.5 years as shown in figure 1.

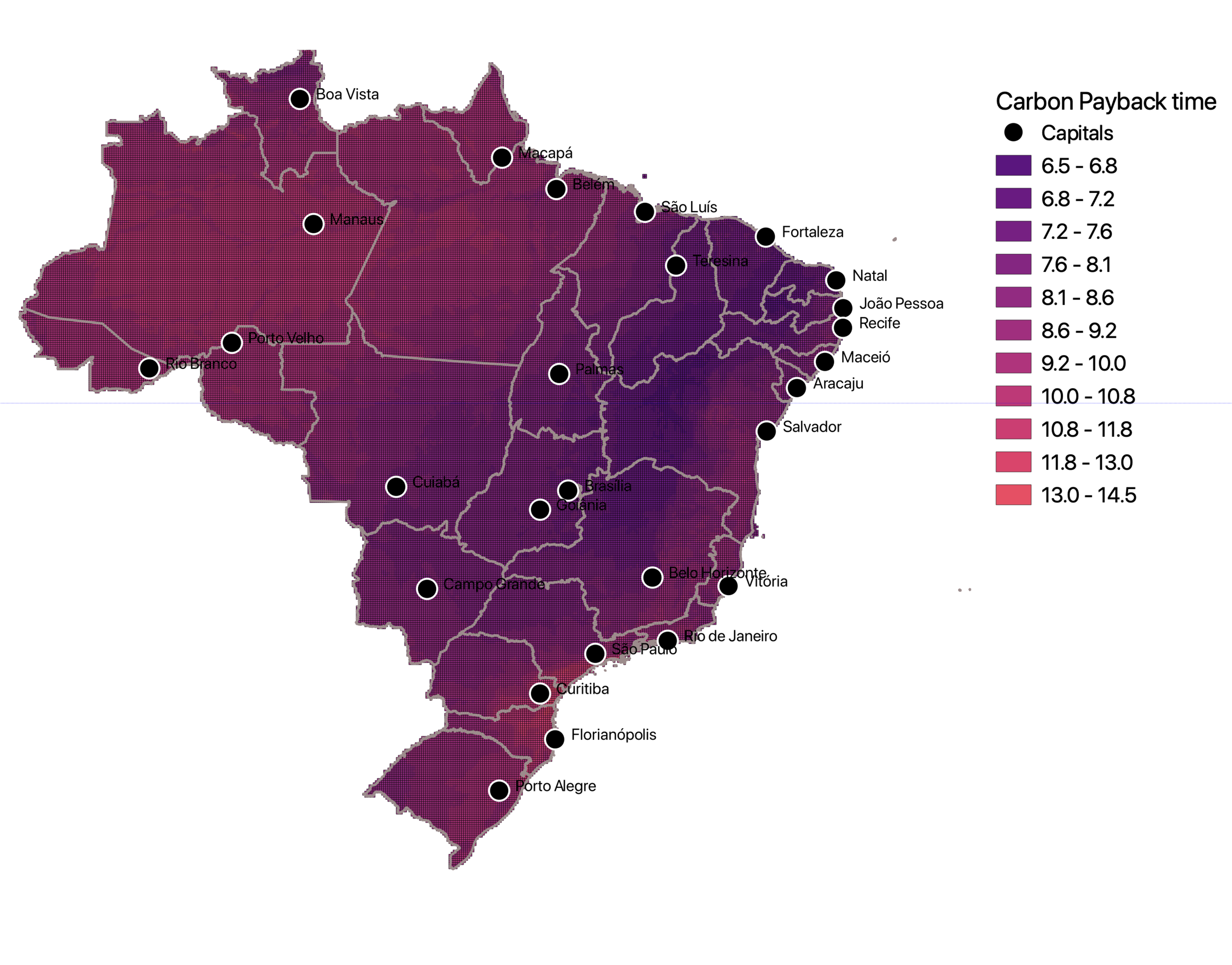

Figure 1: Brazilian's Carbon Payback time heatmap.

The equivalent carbon dioxide amount released during the power plant 25 years lifetime is 1.62x10^6 kg of CO_2, being the manufacturing process responsible for 99.1% and transporting 0.9%. Due to the complexity to estimate the transportation emissions, it was considered the average value to transport all the PV panels from China to the 26 state capitals and the Federal District of Brazil.

Analyzing more closely the 1 MWp PV plant equivalent carbon dioxide released due to the manufacturing process, the panel's fabrication is the major player releasing 1.33x10^6 Kg of CO_2. Figure 2 reveals the contribution of each equipment of the solar power plant.

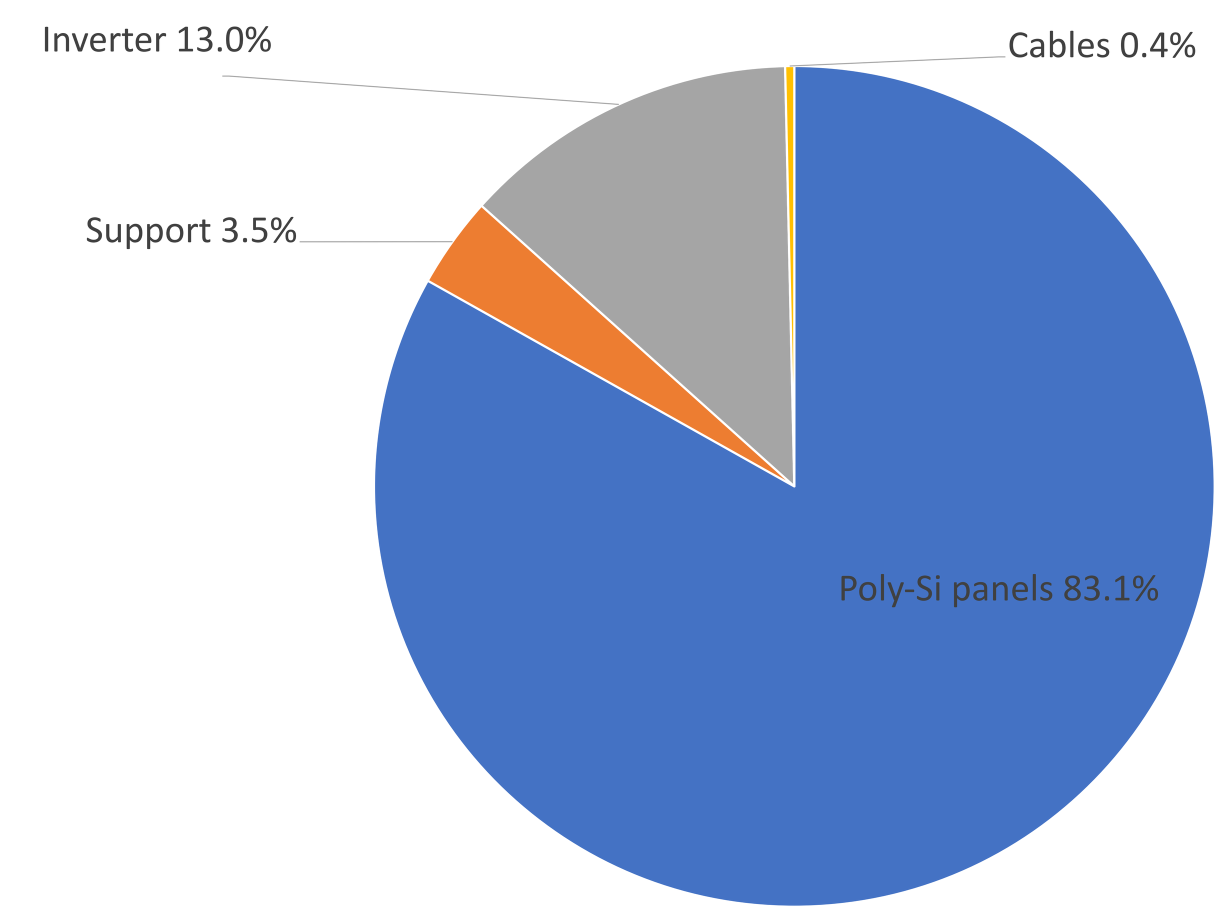

Figure 2: PV plant's equipment emisson contribution.

Conclusion

The study investigated the Carbon Payback Time of a typical 1-MW on-grid rooftop-mounted poly-Si station under Brazilian solar resource, demonstrating that a PV plant can offset its emissions in 6.5 years to 14.5 years. The findings are summarized below:

- The PV technology insertion in the Brazilian grid is beneficial to climate change mitigation and goes toward the Brazilian Nationally Determined Contribution (NDC) to the Paris Agreement that defines a target share from non-hydro renewables of at least 23% of the national electricity matrix by 2030;
- Although the values of equivalent CO_2 emissions of the manufacturing process of solar panels, cables, inverter, and mounting system is significant, the establishment of the solar power station is still environmentally friendly in Brazil;
- The result of this study is somehow theoretical due to the limitations of calculating the logistic emission of installing a PV plant in any location in Brazil. Likewise, it is not possible to connect a PV system to the national grid depending on its location;
- The data used in this study when calculating the manufactory emission is relatively old, meaning that the result would be pessimistic to some extent;

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