Assessing the Alignment of Solar Facilities with Global Climate Goals

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***Abstract* — Climate science-based targets have become the state-of-the-art approach for greenhouse gas goal setting by companies and institutions. As companies try to maximize the climate benefit of their renewable energy investments and lower their Scope 3 emissions, climate science-based target setting can be extended to solar facilities themselves. By evaluating the embodied carbon and economic emissions intensity of a solar facility and globally extrapolating, the solar park's temperature alignment can be calculated with the X-Degree Compatibility Model. A case study of 100 MWdc solar facilities in North Carolina indicates that solar facilities are well aligned with global climate goals for a 1.75°C (i.e. 'well below 2°C') warming scenario. While the analysis shows that both, CdTe and mono-c-Si PV systems, are compatible with the chosen global warming scenario, the CdTe PV system has a lower climate impact, measurable in °C. The most sensitive variables contributing to economic emissions intensity are PPA price, O&M cost, system lifetime, and embodied carbon. Continued progress in lowering the embodied carbon and increasing the lifetime of PV systems is needed to counteract the tendency for increasing economic emissions intensity from declining PPA prices.**

I. Introduction

Efforts to mitigate global climate change have evolved beyond central government action, with corporate and regional entities establishing individual metrics and targets. The most sophisticated methods for target setting are known as climate science-based targets [1], in which global greenhouse gas (GHG) emissions scenarios (e.g., 1.75°C or 2°C warming scenarios) are used to estimate allowable emissions for a given company or entity.

While solar photovoltaic (PV) facilities have no direct GHG emissions during operation, they have emissions over the system life cycle, particularly in the production of components, as well as during construction and decommissioning. These life cycle emissions have an important role in the net displacement of grid electricity GHG emissions by solar energy projects [2].

As corporate and regional entities make procurement decisions for solar energy, they are beginning to advocate for decarbonizing the solar supply chain [3]. Since the embodied carbon of purchased electricity is part of Scope 3 GHG accounting [4], these efforts would lower a buyer's Scope 3 emissions and maximize the climate benefit of their investments.

This study provides a quantitative method for solar energy buyers to assess the alignment of solar facilities with global climate goals (concretely, with IEA's B2DS scenario which is a 1.75°C warming scenario [5]). The method is applied to ground-mount solar facilities, with identification of key system parameters that influence alignment.

II. Methods

The analysis is based on the X-Degree Compatibility (XDC) model [6], version 2.0, which utilizes four steps:

1) What quantity of emissions (CO_2-eq) does the facility generate per unit of gross value added (GVA; $) from a base year to 2050?
2) What quantity of emissions (CO_2-eq) would reach the atmosphere if the entire world operated as emission intensively until 2050 as the facility under consideration?
3) What degree of global warming would be expected if that quantity of emissions reached the atmosphere?
4) What is the difference between the solar park's XDC calculated in step 3 and the sector-specific Target XDC? This results in the XDC Gap. A positive XDC Gap indicates misalignment with the 1.75°C scenario while a negative XDC Gap indicates alignment with the 1.75°C scenario.

For step 1, electricity production from a 100MWdc utility-scale 1-axis tracking facility in North Carolina, USA with 30-year system lifetime and 1.25 DC:AC ratio was modeled with PlantPredict software, using both cadmium telluride (CdTe; 1730 MWh/MWdc/yr 1st year specific yield; 0.2%/yr degradation rate) and mono-crystalline silicon (mono-c-Si; 1712 MWh/MWdc/yr 1st year specific yield; 0.5%/yr degradation rate) PV module technology. A 2019 average U.S. power purchase agreement (PPA) price of $24/MWh [7] was used in conjunction with electricity production to estimate annual revenue. GVA is defined as PPA revenue minus operations and maintenance (O&M) expenses ($10/kWdc per yr) [8] minus decommissioning costs ($83/kWac) [9] in a given year. Note all financial values are considered as 2018 constant $.

Also, for step 1, the quantity of life cycle emissions are from the IEA PVPS (2020) life cycle inventory [10] implemented in Simapro 9.2.0.1 software with UVEK DQRv2:2018 background database and IPCC 2013 GWP 100a impact method (705 and 1177 metric tons CO2-eq/MWdc for CdTe and mono-c-Si ground-mount PV systems, respectively; production in USA/Malaysia and China, respectively). Of these life cycle emissions, 4.4% and 2.9% are assumed to occur during decommissioning for CdTe and mono-c-Si ground-mount PV systems, respectively [11], and the remainder are due to the supply chain of components and facility construction. During project operation, minor GHG emissions are estimated with electricity use for 1-axis tracking (2.35 MWh/MWdc per yr) [12] using the life cycle carbon intensity of the regional electricity grid (SERC; 0.621 metric tons CO2-eq/MWh; Ecoinvent 3.6).

For step 2, annual GHG emissions are normalized by annual GVA to obtain annual economic emissions intensity (EEI). The facilities' GHG emissions are not emitted directly by the facility (Scope 1) but are indirect emissions (Scope 2 or 3) [4].

In the XDC model, indirect emissions are weighted by 50% by convention [6]; hence, the EEI is weighted by 50%. Because the annual EEI is heterogeneous over the system lifetime with most emissions occurring initially, effective EEI is also calculated as a constant value that leads to the same upscaled cumulative emissions when multiplying with the global GVA. Global emissions are obtained by multiplying the solar facility's effective EEI by global GVA ($73.8 trillion in 2018; 1.93% annual growth rate) [13] through 2050.

For step 3, global emissions estimated in step 2 are used as input to the FaIR climate model [14] to estimate global warming associated with these emissions.

In step 4, the results are compared to the sector-specific Target XDC since the contribution to global warming and the leverage for emissions reductions differs between sectors [6]. The Target XDC is the benchmark which actors in the energy sector (OECD region, NACE 35, electricity, gas, steam, and air conditioning supply) should reach in order to be aligned with the chosen 1.75°C scenario (B2DS scenario).

III. Results and Discussion

Based on the inputs for step 1 and 2 of the XDC Model, the EEI and effective EEI for CdTe and mono-c-Si ground-mount PV systems are shown in Fig. 1. As explained above, the EEI is highest initially due to the embodied carbon in the PV system components and facility construction activities, and has a smaller peak at project end due to decommissioning. The effective EEI is the constant EEI which is calculated as described above.

When the effective EEI values are globally extrapolated and input to the FaIR climate model (XDC steps 2 and 3 above), they give an XDC of 1.8°C for CdTe and 2.1°C for mono-c-Si PV systems. In both cases, the ground-mount PV facilities are well within the sector-specific benchmark for the NACE 35 sector of 3.2°C, resulting in XDC Gaps of -1.4 and -1.1°C, respectively. Hence the solar facilities are aligned with 1.75°C of global warming. However, the difference between PV systems is also apparent in their XDCs, with the CdTe PV system's climate impact 0.3°C lower than for mono-c-Si PV.

In order to understand the main contributors to the temperature alignment, model parameters were varied (Table 1). Several parameters influence the GVA estimate, including PPA price, O&M and decommissioning cost, energy yield, and degradation rate. Of these variables, the PPA price and O&M cost are most sensitive. PPA prices have been declining with time and scale of PV deployment [7], resulting in a tendency to increase the climate impact as measured by the XDC Model as less GVA is created. This is partly offset by a trend of decreasing O&M costs.

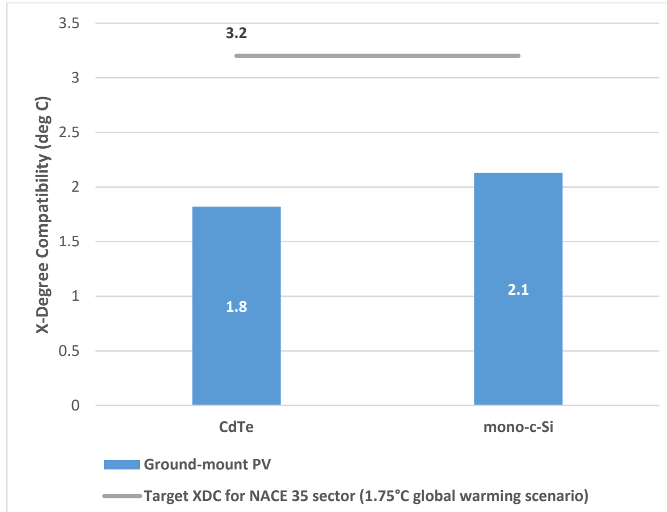

Fig. 2. Alignment of solar facilities with global climate goals. NACE 35 refers to electricity, gas, steam, and air conditioning supply sector in OECD region.

The EEI is estimated by normalizing annual GHG emissions by annual GVA. While the annual GVA is tending to decrease due to lower PPA prices, the annual GHG emissions are also tending to decrease with time and scale of PV deployment [10]. The sensitivity analysis in Table 1 and Figure 3 shows that embodied carbon is a sensitive model parameter along with PPA price and O&M cost.

Lastly, the system lifetime is also a sensitive parameter that influences EEI, with longer lifetimes reducing the effective EEI, since emissions are normalized over a longer duration. Improvements in PV module and system stability [15] can help counteract the tendency toward increasing EEI from lower PPA prices.

With regards to the OECD NACE 35 sector benchmark (3.2°C), the sensitivity analysis shows that ground-mount PV systems are compatible with this sector benchmark under the various model parameter variations. All the cases analyzed in

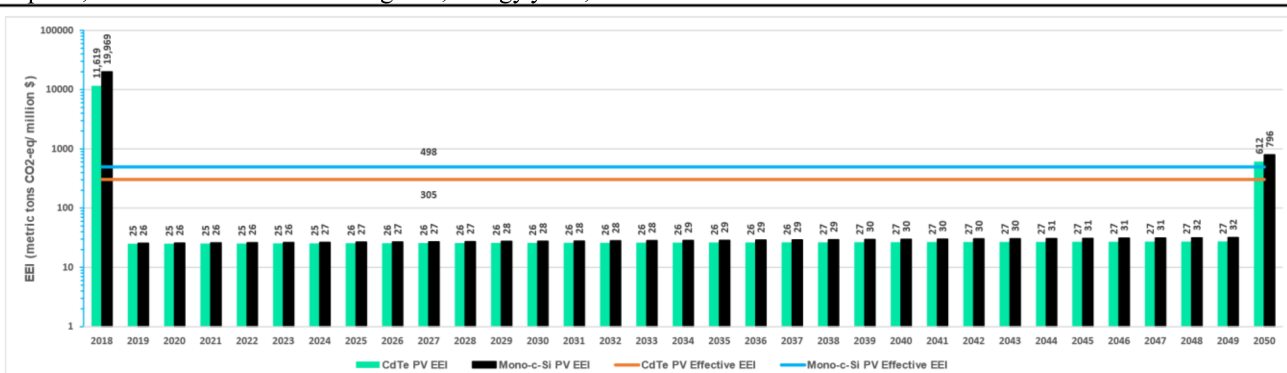

Fig. 1. Economic emissions intensity (EEI; log-scale) for 100 MWdc ground-mount PV systems in North Carolina.

Table 1. Sensitivity analysis of model parameters

	Model parameter		X-Degree Compatibility in °C		X-Degree Compatibility Gap Compared to NACE 35 sector target (3.2°C)	
	Low	High	Low	High	Low	High
O&M ($/kWdc per yr)	4	14	1.7	1.9	-1.3	-1.5
Decommissioning ($/kWac)	40	80	1.7	1.8	-1.5	-1.5
PPA price ($/MWh)	20.00	40.00	1.6	1.9	-1.3	-1.7
Embodied carbon (metric tons CO2e/MWdc)	705	3047	1.8	3.0	-0.2	-1.5
End-of-life fraction of embodied carbon	1.60%	6.60%	1.7	1.8	-1.4	-1.5
Tracking electricity usage (MWh/MWdc per yr)	1.50	3.00	1.7	1.8	-1.4	-1.5
Life cycle grid electricity carbon footprint (SERC; metric tons CO2e/MWh)	0.200	0.700	1.7	1.8	-1.5	-1.5
1st yr specific yield (MWh/MWdc/yr)	1700	1800	1.7	1.8	-1.4	-1.5
Degradation rate (%/yr)	0.1%	0.5%	1.8	1.8	-1.4	-1.5
Lifetime	25	33	1.7	1.9	-1.3	-1.5

Table 1 fall within this benchmark. However, when running the analysis with very high values for embodied carbon, the solar facility's climate impact is only slightly within the sector-specific Target XDC. Therefore, continued progress in lowering the embodied carbon in PV systems is crucial for maintaining compatibility with climate goals. The EPEAT registry for sustainable electronics is developing criteria for low carbon PV modules that can further incentivize reductions in embodied carbon [16].

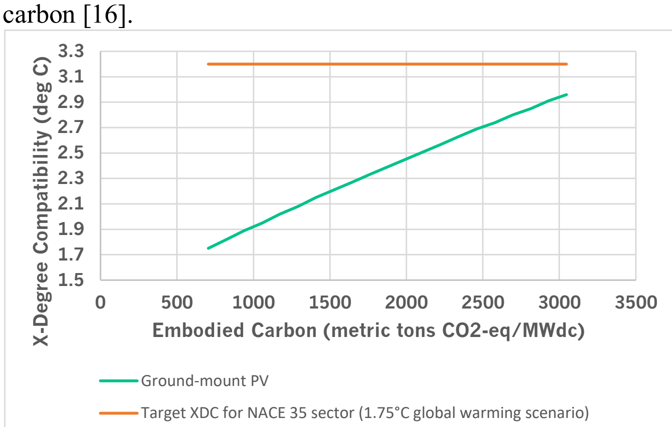

Fig. 3. Sensitivity analysis of X-Degree Compatibility with embodied carbon for 100 MWdc ground-mount PV systems in North Carolina. Lower and upper bound values for embodied carbon are from [10] and [17], respectively.

IV. Conclusions

Assessment of the economic emissions intensity of ground-mount PV facilities indicates that they are aligned with global climate change and OECD electricity sector-specific goals for a 1.75°C warming scenario. The most sensitive variables contributing to economic emissions intensity are PPA price, O&M cost, system lifetime, and embodied carbon. Continued progress in lowering the embodied carbon and increasing the lifetime of PV systems is needed to counteract the tendency of increasing economic emissions intensity from declining PPA prices.

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