LIFE CYCLE ASSESSMENT OF UTILITY-SCALE CDTE PV BALANCE OF SYSTEMS

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ABSTRACT: The LCA carbon footprint of utility-scale CdTe PV BOS consists predominantly (50-66%) of mounting materials (e.g., steel, aluminum, synthetic rubber), with smaller important contributions from cabling, inverters, transformers, and raw material transport. Construction and operations and maintenance (O&M) only contribute to 4-7% of the total BOS carbon footprint. Previous analysis of roof-mount and ground-mount CdTe PV BOS ranges from carbon footprint of 5.7-8.5 g CO2e/kWh and energy payback time and non-renewable energy payback time (EPBT/NREPBT) of 0.20-0.32 yr. The BOS LCA carbon footprint (4.0-6.0 g CO2e/kWh) and EPBT/NREPBT (0.21-0.28 yr) in this evaluation is consistent with these estimates, after harmonizing to the same irradiation levels. Because the LCA carbon footprint and EPBT/NREPBT of utility-scale CdTe PV BOS is not considerably higher than that of rooftop CdTe PV BOS, utility scale deployment of CdTe PV can provide rapid grid penetration with comparable environmental benefits to roof-top CdTe PV.
Keywords: BOS, LCA, CdTe, Thin Film, Large Grid-connected PV systems

1 INTRODUCTION

Utility-scale ground-mounted solar photovoltaic (PV) plants provide the economies of scale and rapid market penetration needed to further the transition to renewable energy sources. While the balance of system (BOS) requirements of ground-mounted PV differ from rooftop installations, Mason et al. (2006) has shown that the life cycle impacts of ground-mount BOS are significantly lower than originally predicted, as demonstrated with a 3.5 MWp multi-crystalline silicon (Si) PV installation in the southwest United States (Springerville, AZ) [1].

This evaluation presents a comparable evaluation of ground-mount BOS life cycle impacts for a planned thin-film (cadmium telluride; CdTe) 550 MWac PV installation in the southwest United States (San Luis Obispo County, CA) [2]. This assessment evaluates the life cycle carbon footprint, energy payback time (EPBT), and non-renewable energy payback time (NREPBT) of utility-scale CdTe PV BOS. These metrics are relevant to understanding potential environmental impacts for the current large (multi-GW) project pipeline for CdTe PV in North America [3].

2 DATA COLLECTION

A life cycle inventory (LCI) has been developed based on a detailed BOS mass mechanical record for the planned 550 MWac Topaz Solar Farm in San Luis Obispo County, California. Construction of this project commenced in 2012 and is expected to continue over three years. The life cycle inventory is structured in accordance with International Energy Agency Photovoltaic Power Systems Program (IEA PVPS) Task 12 guidelines for life cycle assessment (LCA) of PV [4], including data for the following categories: mounting, cabling, inverter, transformer, site construction, and operations and maintenance (O&M). LCA carbon footprint and EPBT/NREPBT estimates are based on Q2 2012 average module conversion efficiency of 12.6% [5]. Project-specific data on performance ratio (0.812), plane of array irradiation (2199 kWh/m^2/yr), and module degradation rate (0.70%/yr) have been obtained in the fourth quarter of 2011 from First Solar's performance engineer utilizing PVsyst V. 5.52 software (C. Schwartz, personal communication). A 30-60 year lifetime for mounting materials, and 30 year lifetime for other BOS components have been assumed [4].

Mounting and cabling components include steel, concrete, wood, copper, polyethylene composite material (HDPE), aluminum, synthetic rubber (EPDM), and PVC plastic (Table 1). Electrical components include the use of 500 kWp inverters and 1 MWp transformers. The Ecoinvent (V. 2.2) unit process for a 500 kW inverter was used to model inverters (including 10% part replacement every 10 years and an inverter sizing ratio of 0.93 kVa/kWp [7]), whereas the transformer components (steel, copper, plastic, transformer oil, other) from Mason et al. (2006) were used to model transformers [1].

Use of fuel and electricity for construction and O&M were also included in the inventory (Table 2). In addition, water usage and wastewater discharge to municipal treatment (each estimated at a total of 89 kg per m^2 module over the 3 year construction period and 30 year operating period) were considered, as was transport of packaged modules via transoceanic freight ship from the manufacturing site, Kulim, Malaysia, to the installation site, San Luis Obispo County, California (274 tonne-km per m^2 module).

The BOS design for this project accounts for wind and snow load of 137 km/hr and 24 kg/m^2, respectively. Figure 1 is an image of the mounting structure evaluated in this study.

Figure 1: Mounting structure for a utility-scale CdTe PV project.

Table 1. Material inventory of the mounting and cabling BOS components for a utility scale CdTe PV plant.

				Other Support Structures		
Material	Unit	Mounting	Cabling	Conduits and Fittings	Concrete pads and footings	Wood posts
Steel (not zinc coated)	kg/m^2 module	0.0625	-	-	-	-
Steel (zinc coated)	m^2/m^2 module	0.6311	-	-	-	-
	kg/m^2 module	10.14	-	-	-	-
Aluminum	kg/m^2 module	0.1342	0.0374	-	-	-
Copper	kg/m^2 module	-	0.8798	-	-	-
Polyethylene Composite Material (HDPE)	kg/m^2 module	-	0.2866	-	-	-
EPDM (synthetic rubber)	kg/m^2 module	0.0625	-	-	-	-
PVC	kg/m^2 module	-	-	0.04204	-	-
Concrete	kg/m^2 module	-	-	-	3.743	-
Wood	m^3/m^2 module	-	-	-	-	0.001041

Table 2. Material inventory of the construction and O&M BOS components for a utility scale CdTe PV plant.

	Diesel	Electricity	Natural gas	Gasoline
	kg/m^2 module	kWh/m^2 module	m^3/m^2 module	kg/m^2 module
Construction Off-Road Equipment	1.590	-	-	-
Construction On-Road Equipment	0.1292	-	-	-
Construction Water	-	0.1290	-	-
Construction Lighting	-	0.0001045	-	-
Construction Diesel Generators	0.0002912	-	-	-
Operations Office	-	1.030	0.01580	-
Operations Water	-	0.001353	-	-
Operations Lighting	-	0.1252	-	-
Operations Vegetation Maintenance	-	-	-	0.05517

3 METHODS

Life cycle assessment has been conducted with Simapro (V. 7.3.2) software and Ecoinvent (V. 2.2) unit processes. LCA carbon footprint is estimated as CO_2 equivalent (IPCC 2007 GWP 100a Version 1.02 characterization method in Simapro) based on an integrated 100-year time horizon using the 2007 global warming potential factors published by the Intergovernmental Panel on Climate Change.

Energy payback time is defined as the period required for a renewable energy system to generate the same amount of energy (in terms of primary energy equivalent) that was used to produce the system itself (Eq. 1).

$$EPBT = CED / (E_{agen} / \eta_G) \qquad (1)$$

where CED is the cumulative energy demand of the system, E_{agen} is annual electricity generation, and η_G is grid efficiency (California grid; USEPA CAMX eGrid subregion [6]).

The Cumulative Energy Demand Version 1.08 characterization method in Simapro was used to estimate CED, which describes the primary (direct and indirect) consumption of fossil, nuclear, non-renewable biomass, and renewable energy sources along the life cycle of the system. Efficiency of the California grid (η_G) is approximately 31.6% which is similar to that of the average European grid.

The non-renewable energy payback time (NREPBT) is the EPBT calculated using the non-renewable (fossil, nuclear, non-renewable biomass) primary energy only for both the CED and η_G terms in Eq. 1. It therefore represents the time needed to compensate for the non-renewable energy required during the life cycle of the system. Because the electricity grids considered in this evaluation are dominated by non-renewable power generation, there is not a significant difference between EPBT and NREPBT.

4 RESULTS AND DISCUSSION

Because mounting materials are the largest contributors to the BOS LCA carbon footprint (Figure 2) and EPBT/NREPBT, a key variable is the lifetime of mounting materials. IEA Task 12 guidelines for LCA of PV (Fthenakis et al. 2011) recommend a range of 30-60 years for the lifetime of mounting structures for ground mount installations on metal supports. Based on this range, the LCA carbon footprint and EPBT/NREPBT vary from 4.0-6.0 g CO2e/kWh and 0.21-0.28 yr, respectively, in this evaluation (Table 3). Because the electricity grids considered in this evaluation are dominated by non-renewable power generation, EPBT and NREPBT differ only slightly (at the level of a third significant figure not shown in Table 3 due to rounding).

The plane of array irradiation at the project site is relatively high (2199 kWh/m^2/yr). In order to compare the BOS LCA results of this evaluation to other estimates (rooftop CdTe PV BOS [8] and ground-mount CdTe PV BOS [9] [10]), the results may be harmonized to the irradiation (1700 kWh/m^2/yr) considered in the other evaluations. The resulting harmonized carbon footprint (5.2-7.7 g CO2e/kWh) and EPBT/NREPBT (0.27-0.37 yr) in this evaluation overlaps with the range (5.7-8.5 g CO2e/kWh and 0.20-0.32 yr) from the other evaluations. Overall, the LCA carbon footprint and EPBT/NREPBT of utility-scale CdTe PV BOS is not considerably higher than that of rooftop CdTe PV BOS, and is consistent with other recent estimates for ground-mount BOS (Table 3).

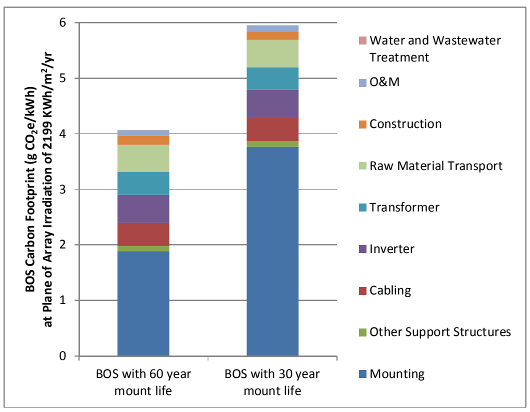

Figure 2: LCA carbon footprint of utility-scale CdTe PV BOS by component. Based on Q2 2012 module conversion efficiency of 12.6% [5], performance ratio of 0.812, California grid (CAMX eGrid subregion) [6], plane of array irradiation (2199 kWh/m2/yr), 0.70%/yr module degradation rate, 30-60 year lifetime for mounting materials, and 30 year lifetime for other BOS components.

4 CONCLUSIONS

The LCA carbon footprint and EPBT/NREPBT of utility-scale CdTe PV BOS is not considerably higher than that of rooftop CdTe PV BOS, and is consistent with other recent estimates for ground-mount BOS. Therefore, utility scale deployment of CdTe PV can provide rapid grid penetration with comparable environmental benefits to roof-top CdTe PV.

5 REFERENCES

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Table 3. Life cycle carbon footprint, EPBT, and NREPBT of CdTe PV BOS.

	Mount	Mounting life	Plane of array irradiation	Module conversion efficiency	Degradation rate	Performance ratio	**Carbon Footprint**	**EPBT**	**NREPBT**
	-	yr	kWh/m^2/yr	%	%/yr	-	g CO_2e/ kWh	yr	yr
This study	Ground	30	2199	12.6	0.67	0.8	6.0	0.28	0.28
	Ground	60	2199	12.6	0.67	0.8	4.0	0.21	0.21
	Ground	30	1700	12.6	0.67	0.8	7.7	0.37	0.37
	Ground	60	1700	12.6	0.67	0.8	5.2	0.27	0.27
[8]	Roof	30	1700	11.3	0.67	0.75	5.7	0.22	-
[9]	Ground	30	1700	10.9	Not available	0.8	-	0.32	-
[10]	Ground	30	1700	10.9	0.5	0.8	8.5	-	0.20

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