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LIFE CYCLE CARBON FOOTPRINT ASSESSMENT OF A LOW-CARBON SOLAR PV TRACKER

Summary

This study conducts a Life Cycle Assessment (LCA) of solar photovoltaic (PV) trackers, comparing a traditional design with a new low-carbon option. Solar trackers are known to increase energy production by up to 30%, resulting in greenhouse gas (GHG) emissions throughout their lifespan. The baseline system employs steel using the Blast Oxygen Furnace (BOF) method, whereas the enhanced design uses recycled steel produced via Electric Arc Furnace (EAF) technology. The results show that sourcing materials locally, utilizing sustainable packaging, and opting for EAF steel can cut emissions by as much as 42%. These outcomes underscore the vital importance of sustainable design in renewable energy and environmental science.

Keywords: Life Cycle Assessment, Carbon Footprint, PV Tracker, EAF Steel, Sustainable Design

1. Introduction

Solar photovoltaic (PV) trackers are essential for boosting the energy output of utility-scale solar power plants by continually adjusting the positioning of PV modules to follow the sun's path. This tracking capability can increase energy production by up to 30% compared to fixed-tilt systems (SolGen Power, 2025). Despite their performance benefits, PV trackers have an unavoidable environmental impact due to emissions generated throughout their life cycle, including raw material extraction (particularly steel), manufacturing, transportation, operation, and end-of-life disposal.

To promote the development of more sustainable solar infrastructure, a comprehensive Life Cycle Assessment (LCA) was conducted to quantify the carbon footprint associated with photovoltaic (PV) tracker systems. This assessment adhered to international standards ISO 14040, ISO 14044, and ISO 14025, ensuring a rigorous approach to environmental impact evaluation. It incorporated relevant Product Category Rules (PCR) specified in PCR 2019:14, which are tailored to construction products and complementary cradle-to-product life cycle (c-PCRs) specifically designed for solar applications. By evaluating each stage of the PV tracker systems—from material extraction and manufacturing to installation, operation, and end-of-life disposal—this LCA provides critical insights into the sustainability of these systems and identifies opportunities for reducing their environmental impact throughout their entire life cycle.

The LCA compares two distinct cradle-to-grave scenarios: a baseline configuration utilizing conventional supply chains alongside steel produced via the Blast Oxygen Furnace (BOF) method, and an enhanced scenario incorporating regionally sourced components and steel manufactured through the Electric Arc Furnace (EAF) process using post-consumer recycled scrap. The latter approach has demonstrated a potential reduction in greenhouse gas (GHG) emissions by up to 75% per tonne of steel produced (Green Steel World, 2023), a significant reduction that can have a substantial impact on the overall carbon footprint of PV tracker systems, contingent upon factors such as energy source and scrap content.

This innovative study employs a systematic, Life Cycle Assessment (LCA)-driven approach to optimize photovoltaic (PV) tracker system design. The main innovations include:

- *Material Optimization:* replacing the BOF supply chain with lower-carbon steel derived from post-consumer scrap processed through EAF technology.

- *Supply Chain Optimization:* choosing regional suppliers strategically, shortening transportation distances, and lowering logistics-related emissions.
- *Sustainable Materials for Products and Packaging:* replacing plastic components with recyclable steel and utilizing recyclable packaging materials to mitigate end-of-life impacts.

These integrated innovations in product design and supply chain management create a highly scalable model to significantly reduce environmental impacts associated with photovoltaic (PV) trackers. By utilizing advanced materials that are both lightweight and durable, alongside streamlined assembly processes, this approach not only enhances operational efficiency but also minimizes resource consumption. Additionally, implementing sustainable sourcing practices ensures that raw materials are harvested responsibly, while renewable energy is prioritized throughout the manufacturing stages. Collectively, these efforts set a new benchmark for sustainable development in the PV tracker industry, promoting long-term ecological balance and advancing the transition towards clean energy solutions.

2. Materials and Methods

This study employed a comparative LCA to assess the carbon footprint of two solar PV tracker configurations. The first configuration (Scenario 1) represents a conventional PV tracker made from steel produced through the BOF process, reflecting standard supply chain practices. The second configuration (Scenario 2) offers a low-carbon alternative that includes modifications such as the use of post-consumer scrap steel processed via EAFs and regionally sourced components to reduce emissions associated with transportation.

The assessment followed a *cradle-to-grave approach* and was conducted in alignment with international standards ISO 14040, ISO 14044, and ISO 14025 for Environmental Product Declarations (EPDs). The analysis also adhered to the Product Category Rules (PCR 2019:14) for construction products and complementary PCRs (c-PCRs) specific to solar PV trackers, with impact characterization factors based on EN 15804+A2.

The methodology was structured into four main phases:

- *Goal and Scope Definition:* Establish the purpose of comparing the two tracker scenarios while defining the system boundaries, functional unit, and assumptions. The goal is to identify differences in life cycle GHG emissions and determine the primary emission "hotspots."
- *Life Cycle Inventory (LCI):* Collect primary and secondary data across all life cycle stages, including raw material acquisition, manufacturing, assembly, transportation, installation, use phase (if applicable), and end-of-life treatment. Data sources include suppliers, processing documentation, and recognized LCA databases.
- *Life Cycle Impact Assessment (LCIA)*: Quantify the environmental impacts associated with each scenario, focusing on the potential for climate change. The EN 15804+A2 method (IPCC GWP 100a) was applied using the SimaPro® software tool, supported by the Ecoinvent 3.10 database, Industry Data 2.0, and the U.S. Life Cycle Inventory (USLCI).
- *Interpretation:* The LCA results are analyzed and compared using contribution and scenario analysis. A sensitivity analysis was performed to evaluate the robustness of the findings and assess the influence of key parameters, such as steel production technology and transportation distances.

3. Results

The following figure (Fig. 1) demonstrates the key differences in carbon footprints between traditional solar PV trackers and their low-carbon alternatives:

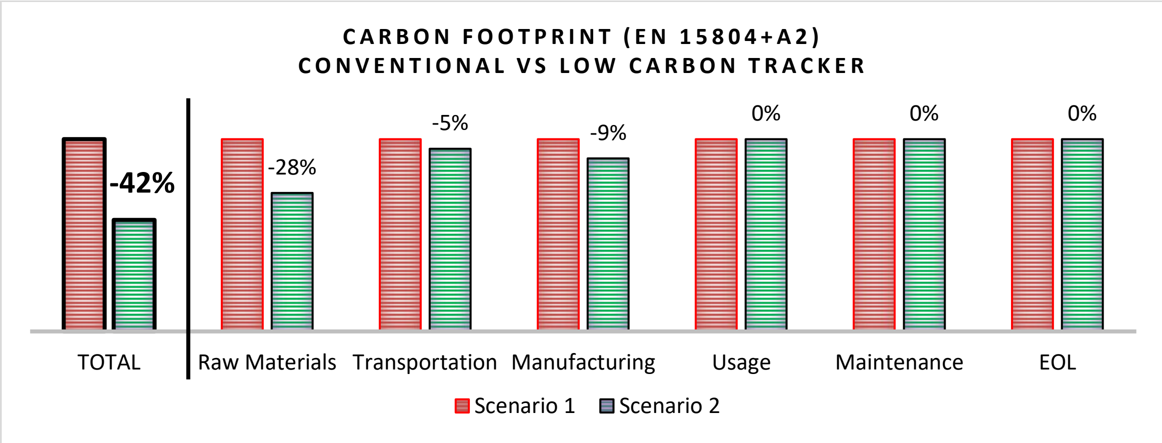

Fig. 1: Comparison of Carbon Footprint from the conventional (Scenario 1) and low-carbon tracker (Scenario 2).

The results compare the carbon footprints between a conventional solar PV tracker and a low-carbon version, adhering to the EN 15804+A2 methodology. Overall, there is a 42% reduction in greenhouse gas emissions for the low-carbon configuration (Scenario 2) compared to the conventional tracker (Scenario 1). The most significant reductions, amounting to 28%, occur during the raw materials stage, primarily driven by using recycled steel from EAF processes rather than traditional BOF steel. Emissions during the manufacturing phase are diminished by 9%, attributed to enhanced efficiency in processes and improved sourcing techniques. In comparison, transportation emissions experience a decrease of 5% as a result of regionalized supply chains. The utilization, maintenance, and end-of-life (EOL) stages reflect the same values in both scenarios, since no changes were implemented in the modeling assumptions during these phases. Functional performance, usage conditions, and end-of-life treatments were kept constant to guarantee comparability with upstream improvements. These results highlight how material and logistics interventions effectively minimize the overall environmental impact of PV tracker systems.

This study demonstrates that incorporating LCA insights into the design of photovoltaic (PV) trackers can significantly enhance engineering and logistical efforts to improve sustainability without compromising product performance. Selecting appropriate materials and optimizing the supply chain are critical factors for PV solar trackers, as these strategies can substantially reduce the embodied carbon associated with PV infrastructure.

Expanding these practices throughout the entire PV solar tracker industry holds the potential to reduce GHG emissions significantly. According to forecasts from Wood Mackenzie, an estimated 195 GWdc of new utility-scale solar capacity is expected to be added between 2024 and 2029. If a 42% reduction in emissions is realized, this could translate to a decrease of approximately 8.6 million tCO2e. Such a reduction would notably impact the effort to reach net-zero emissions targets.

4. References

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