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LIFE CYCLE ASSESSMENT OF TWO FLOATING PHOTOVOLTAIC SYSTEMS WITH FOCUS ON FLOATING SUBSTRUCTURES

Summary

Floating photovoltaic systems (FPV) offer a promising opportunity to expand solar energy production without competing for land resources. This study evaluates the environmental performance of floating substructures used in two FPV systems in North Rhine-Westphalia using a life cycle analysis (LCA). The complete FPV systems are evaluated in an overall assessment, complemented by an analysis focusing solely on the carbon footprint of the floating support structures. The results show significant differences in CO_2 emissions depending on the design and material composition. By comparing substructures made of steel and a steel-HDPE hybrid construction, the study identifies the most important factors for environmental impact and possible optimization strategies. The results contribute to improving the sustainability of FPV system construction and support future environmentally optimized installations.

Keywords: floating photovoltaics, FPV, LCA, life cycle assessment, carbon footprint, solar energy

Field of application for the findings: Sustainable and Solar Energy Transition

Addressed audience: Researchers, FPV system developers, environmental analysts, renewable energy planners

1. Introduction

Floating photovoltaic (FPV) systems are attracting attention as a way to expand solar energy without competing for land use. Using water surfaces like reservoirs, quarry lakes, or irrigation basins, FPV systems can help expand renewable energy capacities (Cagle et al., 2020). Previous studies have investigated the technical design and environmental performance of FPV installations (Cazzaniga et al., 2018). However, most assessments focus on the overall system performance rather than the environmental efficiency of individual structural components. In this study, two commercial floating photovoltaic systems are analyzed using a Life Cycle Assessment (LCA). Both analyses initially examined the complete FPV systems - including photovoltaic modules, electrical components, and floating structures - to assess their overall environmental performance. In a second step, the scope was narrowed to the floating substructures alone, enabling a direct comparison of their material composition, structural design, and associated environmental impacts. Because the two systems use different substructure concepts and materials, this approach allows for a comparative evaluation of the efficiency and sustainability of the respective floating designs. While LCA results for complete FPV systems can be compared with existing studies, no comparable assessments were found for floating substructures using a functional unit based on CO_2 emissions per unit of load-bearing capacity. Therefore, this study introduces an additional indicator that specifically quantifies the environmental impact of substructures per unit of structural payload capacity, enabling direct comparison of substructural efficiency in terms of environmental impact.

2. Methodology

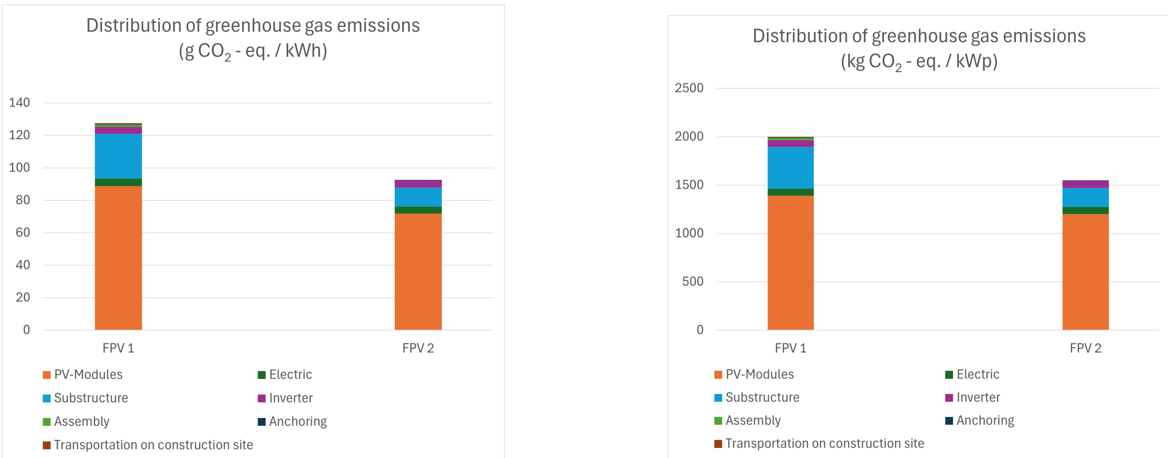
The examined floating photovoltaic systems have installed capacities of 740 kWp and 495 kWp and are located in North Rhine-Westphalia, Germany. Their environmental impacts were assessed using a life cycle assessment (LCA) according to ISO 14040 and ISO 14044, following a cradle-to-grave approach (International Organization for Standardization, 2006a,b). The analysis included photovoltaic modules, inverters, electrical components, floating substructures, and anchors. Functional units were 1 kWh of energy produced and installed capacity (kWp), considering service lifetimes of 20, 25, and 30 years. The floating substructures were evaluated separately using g CO_2 per kg of load-bearing capacity to enable comparison of material efficiency and environmental impact. Data sources comprised primary manufacturer information and secondary literature and databases; missing datasets (e.g., galvanized steel) were modeled in SimaPro 10.2 with the Ecoinvent database (Ecoinvent Association, 2023). Annual energy production was simulated with PVGIS, accounting for degradation and system losses, and environmental impacts were calculated using the Environmental Footprint 3.1 method, with a focus on climate change (GWP100, CO_2 eq.) (European Commission, 2025) (European Commission, 2021).

3. Preliminary Results

3.1 Brief description of both systems

Two floating photovoltaic systems in North Rhine-Westphalia (Germany) were analyzed. FPV1, has an installed capacity of 740 kWp and uses a fully steel-based floating substructure, in which the floats are also made of steel. FPV2, has a capacity of 495 kWp and features a steel support structure with HDPE floats. FPV1 is oriented at 92° (east) an -88° (west), while FPV2 is oriented at 50° (northeast) and -130° (southwest). FPV1 comprises 1896 photovoltaic modules with a nominal power rating of 395 Wp each, while FPV2 comprises 810 modules rated at 610 Wp each. Consequently, minor differences in the life cycle emissions arise between the two systems, motivating the introduction of an additional indicator that quantifies the environmental impact per unit of structural payload capacity to improve comparability.

3.2 LCA results for the entire systems



(a) **(b)**

Fig. 1: Distribution of greenhouse gas emissions by assembly group over a 20-year operating period

The life-cycle greenhouse gas emissions of the two floating photovoltaic systems differ significantly. FPV1 results in total emissions of 127.5 g CO_2-eq/kWh, while FPV2 reaches 92.6 g CO_2-eq/kWh, corresponding to a reduction of approximately 27 %. In both systems, PV modules dominate the environmental impact, contributing about 70-77 % of total emissions. The main difference between the systems is the floating substructure, whose emissions are reduced by about 58 % in FPV2. Other components, such as electrical equipment, inverters and installation processes contribute only marginally to the total life-cycle emissions.

3.3 Results of the floating substructure LCA's

In the second step, the life cycle greenhouse gas emissions of the various substructure components were examined separately. By isolating the substructures from the other system components and introducing a new functional unit, it becomes possible to assess their specific carbon footprint independently of the photovoltaic modules and electrical equipment, which dominate the overall emissions of the system. This approach allows for a clearer comparison of the environmental performance of different design concepts. It provides insights into how the choice of materials and design influences the environmental efficiency of floating photovoltaic systems.

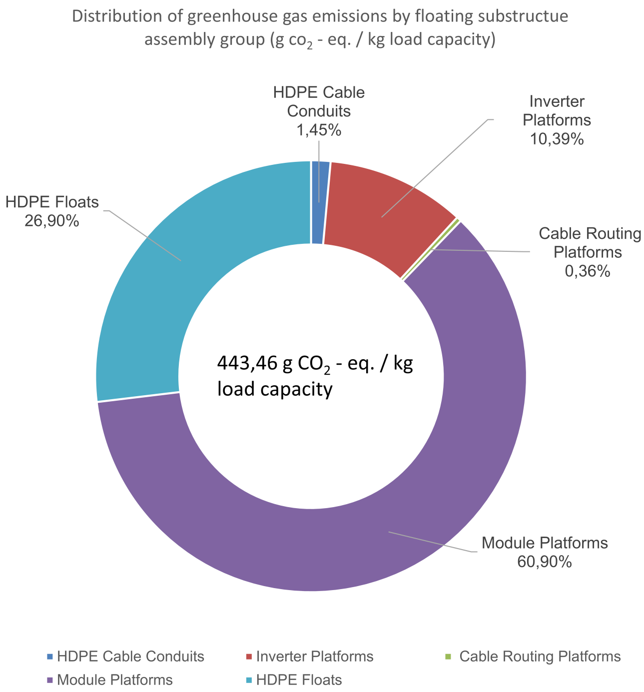


Fig. 2: Breakdown of CO_2 emissions of the floating substructure assembly group for FPV2

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