LCA of a microalgal plant under alternative scenarios: Photovoltaic energy and cultivation in wastewater

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Introduction

Microalgae can serve as a renewable feedstock for a diverse range of bioproducts. However, the environmental sustainability of their production remains uncertain due to the significant variability observed in life cycle assessment (LCA) studies, including those based on primary data from larger-scale pilot installations (Gurreri et al., 2023). Despite that, several assessments have revealed that electricity and nutrient supply are the major impact drivers in microalgae cultivation. Scenario analyses showed potential improvements deriving from grid mixes with higher share of renewable energy or on-site photovoltaic energy (Onorato and Rösch, 2020), waste sources (e.g., wastewater) for nutrient provision (Herrera et al., 2021; Zarra et al., 2024) or both (Pechsiri et al., 2023). However, drawbacks are not excluded. For example, photovoltaic panels, which reduce the global warming potential, can increase other impact categories (related to toxicity), or the use of wastewater, which eliminates the need for impactful chemical fertilizers, may affect the microalgal growth rate.

In this context, this work represents a first step to widen our previous LCA study (performed with primary data from a large-scale pilot plant) (Gurreri et al., 2024) with a scenario analysis that focuses on photovoltaic energy and cultivation in wastewater, assessing their advantages and disadvantages in terms of potential environmental impacts.

Methodology

This LCA study was conducted in compliance with the ISO 14040 (2006) and ISO 14044 (2006) norms. The SimaPro software was adopted along with a spreadsheet to model the product system. The goal of the study is to compare alternative scenarios for energy and nutrient supply with the base case, which was based on the electricity from the Italian grid mix and the use of chemical fertilizers (Gurreri et al., 2024). The microalgal plant is made of tubular PBRs (total volume of ~40 m^3) for cultivating *C. vulgaris* and is installed in a facility located in Caltagirone, Italy. The functional unit was 1 kg of dry-weight biomass (cradle-to-gate assessment). The input and output flows were selected from different sources, mainly the Ecoinvent database (v. 3.9.1). The environmental impacts were assessed through the CML-IA baseline (v. 3.09/EU25) method.

Results

Figure 1 reports the impact assessment results.

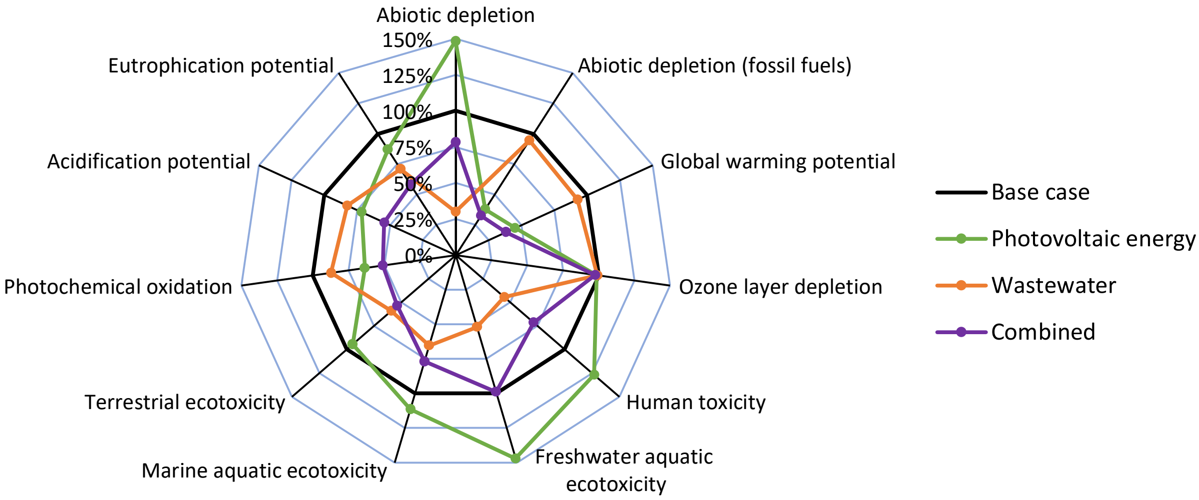

Figure 1. Scenario analysis with relative environmental impacts.

Compared to the Italian grid mix, photovoltaic energy can effectively reduce environmental impacts in seven out of eleven categories, including the global warming potential. However, it worsens the environmental performance in abiotic depletion and the three toxicity impacts.

The cultivation of microalgae in wastewater, which avoids the consumption of chemical fertilizers, brings only potential benefits, though with variable magnitude across the different impact categories. Nevertheless, the assessment was based on the simplifying assumption that the use of wastewater does not affect the biomass growth rate.

Coupling the two strategies, all the environmental impacts are reduced compared to the base case. Indeed, the advantages achieved through the photovoltaic energy in the categories of ADPF, GWP100a, ODP, TETP, POP, AP and EP are in synergy with those of offered by the use of wastewater. Moreover, the wastewater overcompensates the detrimental effects of photovoltaic panels in the ADP, HTP, FAETP and MAETP categories.

Concluding remarks

Photovoltaic energy and wastewater can improve the environmental profile of the assessed microalgal plant. However, these strategies bring drawbacks and challenges. On one hand, photovoltaic panels led to an increase in some environmental impacts. Therefore, the photovoltaic technology cannot be seen as the panacea for improving the environmental performances. On the other hand, microalgae cultivation in wastewater, which was potentially beneficial, poses the risk of a reduced growth rate that would result in a higher amount of various input/output flows and their contribution to the environmental impacts. Therefore, further studies are needed to investigate in more detail the breakdown of contributions, the effects of productivity and additional scenarios.

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