Life Cycle Assessment of Bio-based Materials
Environmental impacts of the value chain from cyanobacteria to PHB

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Introduction

Along with its increasing production quantities, the environmental impact of plastic is posing a progressively serious threat to the environment. Polyhydroxybutyrate (PHB) is a biodegradable biopolymer, which can counteract both the fossil resource depletion and end-of-life issues related to synthetic polymers [1]. Next to those advantages, the production of biopolymers is nonetheless connected to resource consumption and environmentally harmful emissions. For a comparison of such a biopolymer to its synthetic alternative, a life cycle perspective is therefore crucial.

In this context, a life cycle assessment of PHB-producing cyanobacteria cultivated on a thin-layer photobioreactor (PBR) was carried out. The study subject is a pilot plant placed in a greenhouse in Switzerland with a sun-exposed surface of 18 m^2 (see figure 1).

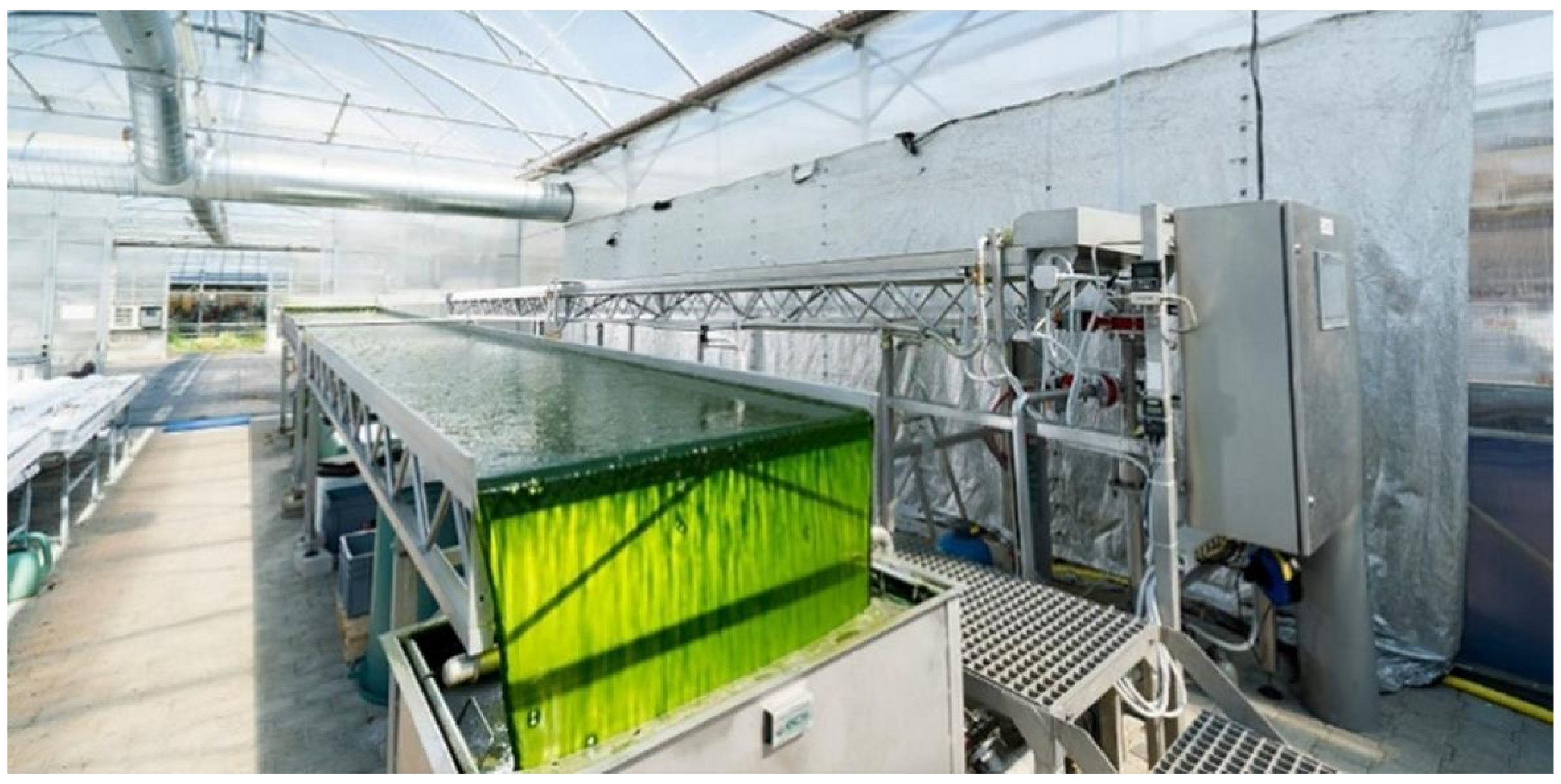


Figure 1. Thin-layer PBR for cyanobacteria production, located at the Institute of Natural Resource Sciences of the Zurich University of Applied Science. Photo: Frank Brüderli

Goal and Scope

The goal of this research was to assess the environmental impact of the PHB-producing cyanobacteria, cultivated on a thin-layer PBR using a standard mineral medium and two wastewater media (aquaculture water and liquid digestate), and extrapolate the data for an industrial scale production scenario.

The foreground data for the life cycle inventory of the cyanobacteria production was based on specific information provided by the Zurich University of Applied Sciences [2]. The foreground data was collected by means of a questionnaire and direct exchange with the contact persons. The system boundaries included the cyanobacteria cultivation, PHB accumulation and centrifugation of the biomass. Consequently, the functional unit was defined as 1 kg of cyanobacteria biomass (dry weight).

Results

The production of 1 kg of cyanobacteria on the pilot scale leads to life cycle greenhouse gas emissions of 35 kg CO_2-eq. when using the mineral medium, which is 2.6 times lower compared to either wastewater medium (see figure 2). Reason for this distinct difference is the yield, which is 3 times higher in the mineral medium. The CO_2 input was identified as the primary hotspot, with a contribution of 60-68% to the total greenhouse gas emissions. Extrapolating the data to an industrial scale scenario, where CO_2 input was minimised while yield was maximised, showed a reduction potential of 90% in all media. Environmental hotspot in this scenario was found to be the electricity consumption, used for pumping systems and centrifuge. The mineral medium scenario on industrial scale shows the potential to compete with the petroleum-based alternatives.

For cyanobacteria production in the mineral medium on industrial scale, certain variability among the different environmental indicators was found (see figure 3). For a majority of indicators, electricity consumption represents the primary environmental hotspot.

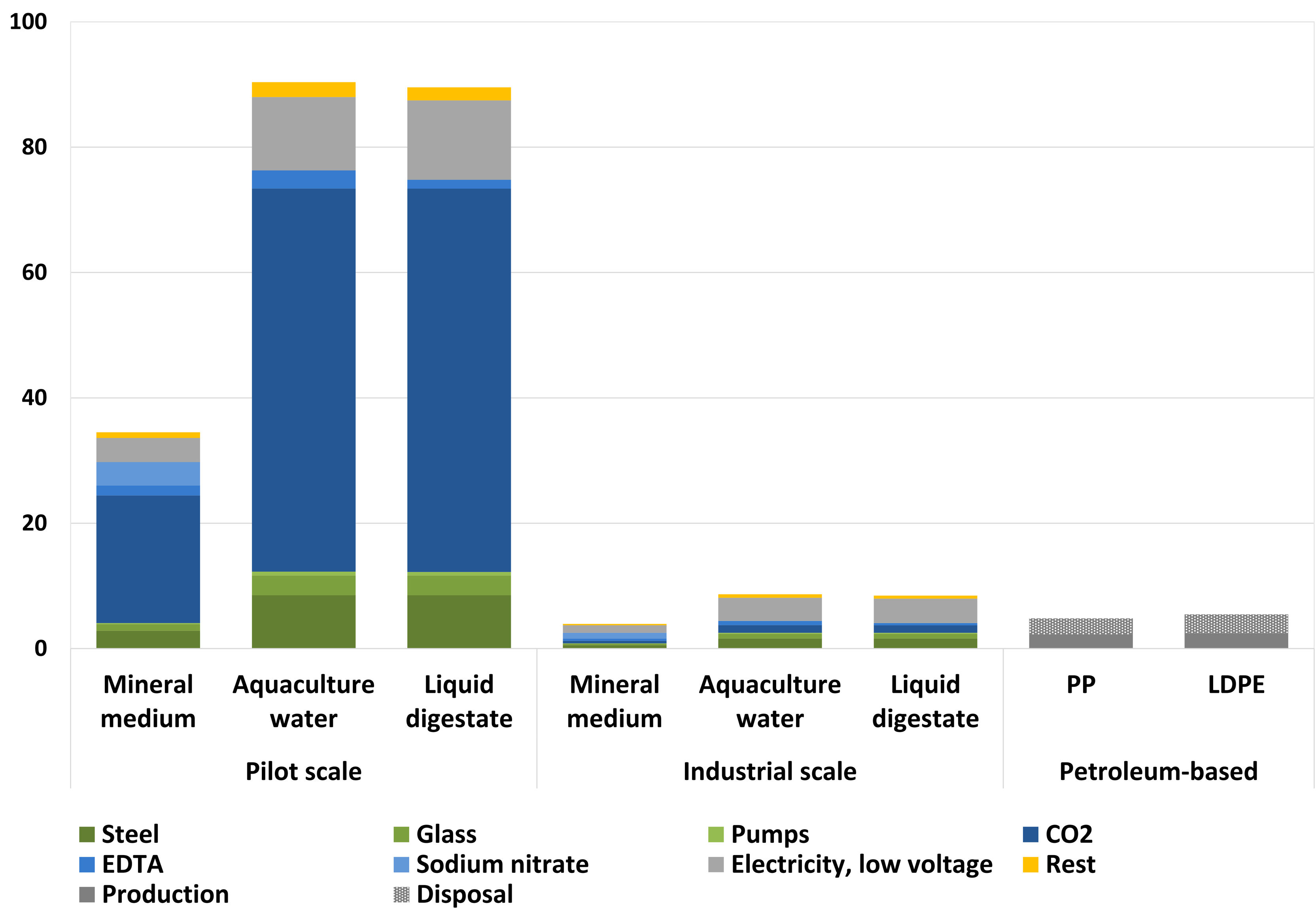


Figure 2. Greenhouse gas emissions in kg CO_2-eq. per kg of cyanobacteria during its life cycle [3], assessed with the IPCC 2021 100a method [4]. Petroleum-based PP and LDPE are included for reference [5].

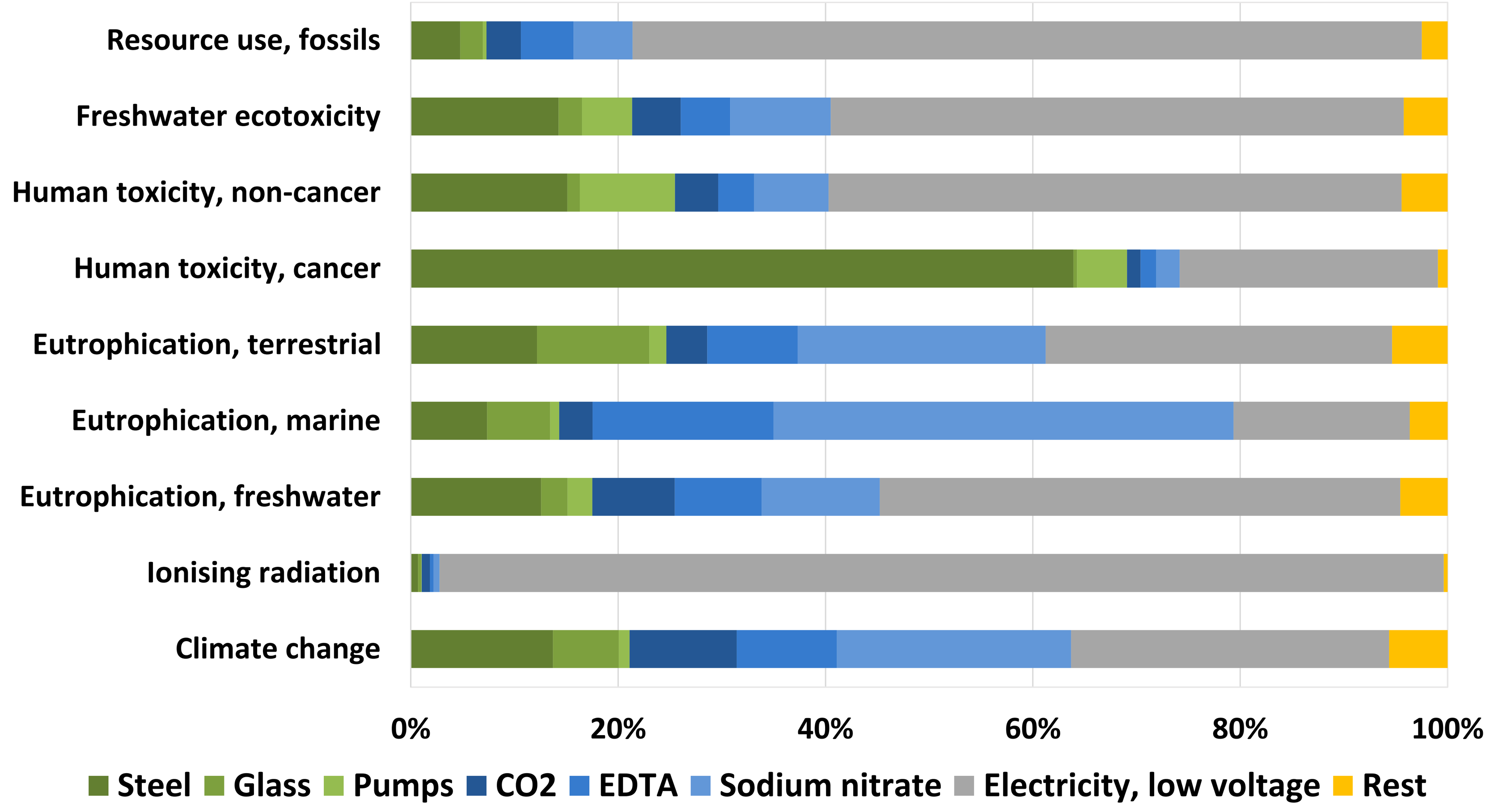
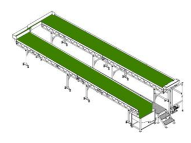
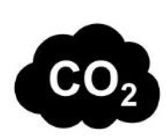


Figure 3. Relative environmental impact during the life cycle of the cyanobacteria production in the mineral medium on industrial scale, based on the Environmental Footprint (EF) [6] and IPCC 2021 method.

Discussion and Conclusion



The use of mineral medium for the cyanobacteria cultivation leads to lower environmental impacts than the wastewater media, due to its significantly higher yield figures.



Reducing the CO_2 input while maximising the yield was found to potentially reduce environmental impacts of up to 91%.

In order to compete with bio-polymers from other feedstock as well as petroleum-based polymers, the electricity consumption further needs to be reduced.

References

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