Sustainable Chemistry: Life Cycle Assessment of High-Demand Biopolymers for Petrochemical Substitution

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Kathleen Meisel, Inga Katharina Götz, Lilli-Sophia Röder, Niels Dögnitz, Karl-Friedrich Cyffka, Arne Gröngröft

DBFZ – Deutsches Biomasseforschungszentrum gemeinnützige GmbH, Torgauer Str. 116, 04347 Leipzig, Germany

Aim and Approach

Defossilisation of the chemical industry is necessary to meet the goals of the Paris Agreement. Several technological approaches, including recycling, renewable feedstocks, integration of renewable hydrogen and carbon capture and usage/storage, must be used in a complementary way to achieve the desired outcome. Besides recycling, biomass feedstocks will be necessary to supply the polymer industry with the required carbon [1]. Therefore, biomass will play a crucial role in the transition of the polymer industry towards non-fossil sources. Biopolymers thus occupy a significant position in the technological approaches.

The aim of this work is to compare life cycle assessments of identified high-demand biopolymer candidates with their respective petrochemical reference materials. With this approach, the environmental performance of the biopolymers can be benchmarked against their potential substitution cases. With an iterative approach, it is aimed to identify the main drivers for different environmental impacts and identify optimisation potentials in the respective production processes.

Scientific innovation and relevance

The presented evaluation is based on the available biomass potential and the demand for different petrochemical polymers in Germany and their respective biopolymer substitutions. From the initial analysis, polylactic acid (PLA), polyamide (PA), polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET) are among the high-demand materials. Each of these polymers is environmentally evaluated based on the compiled mass and energy balances, and benchmarked against the corresponding fossil reference that it is intended to substitute. The limited amount of biomass could be directed to those polymer applications that have the strongest reduction in environmental impact compared to fossil production. By analysing the main drivers of the environmental impacts, the biopolymer production process is scrutinised for optimisation potentials. Industrial partners monitor the iterative process of environmental assessment and optimization while providing their expertise on realistic production processes.

Preliminary results and conclusions

The biopolymer candidates (PLA, PA, PE, PP, PET) are compared to fossil reference polymers according to their global warming potential and a wide range of environmental impact categories (land and resource use, eutrophication, acidification, and ecotoxicity). Optimisations of the production process are proposed and evaluated based on the main drivers. The environmental assessment informs the discussion of renewable feedstocks' role as a complementary pathway to recycling, integration of renewable hydrogen, and carbon capture and storage.

Methods

The available biomass potential and its suitability for biopolymer production was evaluated in the first phase of the GreenFeed project. According to the demand analysis, at least 3 million tonnes of fresh renewable carbon are needed for Germany only [2]. Subsequently, an extensive literature review was carried out to provide an overview of possible biopolymers that could be obtained from this available biomass potential. From these lists, the top candidates have been prioritised according to their technological readiness and the demand for each polymer. These selected biopolymers are the basis for the subsequent analysis.

The life cycle assessments are based on the methods standardised in ISO 14040/14044. The impact assessment is carried out with a cradle-to-gate approach and biogenic carbon is included as a credit to the biopolymer in comparison to the fossil reference. Emission factors are taken from the ecoinvent 3.9 database and the allocation is calculated via the carbon content of the biopolymer and the respective co-products. The IPCC 2021 method is used to calculate the global warming potential and the ReCiPe 2016 midpoint (H) method is applied for other environmental indicators concerning land and resource use, eutrophication, acidification, and ecotoxicity. The life cycle assessments are based on the mass and energy balances of the biopolymer processes derived from scientific literature. Sensitivity analysis is carried out by multiple process variations. Additionally, the identified main drivers are used in an iterative process to suggest and analyse production optimisations.

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Contact Information

Kathleen Meisel (corresponding author): Kathleen.Meisel@dbfz.de, +49 341 2434472

Inga K. Götz:	Inga.Katharina.Goetz@dbfz.de
Lilli-Sophia Röder:	Lilli.Sophia.Roeder@dbfz.de
Niels Dögnitz:	Niels.Doegnitz@dbfz.de
Karl-Friedrich Cyffka:	Karl-Friedrich.Cyffka@dbfz.de
Arne Gröngröft:	Arne.Groengroeft@dbfz.de

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