# Integrated Life Cycle Sustainability Assessment within the early design phase of 2nd generation bio-refinery for downstream production of bio-plastics

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Bio-based materials are oftentimes considered contributors towards a circular economy. The project "BioREFINE-2G: Development of 2nd Generation Bio-refineries" aims at developing commercially attractive processes for efficient conversion of pentose-rich waste-streams from biorefineries into fumaric acid, which can be used to substitute fossil based monomers as precursors for various applications in polymers. An integrated Life Cycle Sustainability Assessment (LCSA) to evaluate the developed process was part of the project and will be presented here.

Circular economy is a normative concept (Ghisellini 2016). We believe it is necessary to aim for large-scale changes including societal behavior, policy as well as technological innovation (Andersen 2007). To ensure that the aim to develop processes contributing to sustainable development are met, measurement is necessary and Life Cycle Perspective is the approach to be taken to make sure that the assessment is holistic. Throughout the BioREFINE-2G project it was the goal to assess the sustainability of a not yet developed synthesis for diacids in comparison to other production routes. The performance of the newly developed fermentation and its periphery is modelled through process interdependencies to calculate impacts of future yields based on empirical data of the early design phase.

The impacts of sustainability measures should be assessed in each dimension of the triple bottom line which includes the ecological, the social and the economic performance (Elkington 1999). According to (Kloepffer 2008) there are two basic approach for the LCSA: (a) combination of three separate analyses for each dimension and (b) an integrated analyses of the three dimensions. Especially during the early design phase, where several analyses, parameter variations and sensitivity analyses are necessary, the integrated approach profits in terms of the efficiency of the analysis process through fast and consistent assessment directly in one model.

For a realistic foreground model of the fermentation, functional relations have been included to predict the nonlinear impacts of different scenarios. The model is based on a cradle to gate environmental Life-Cycle-Assessment (LCA) using primary data from the project partners and ecoinvent v.3.3 background data. For the social assessment (SLCA) a site specific assessment following the approaches from UNEP SETAC (UNEP 2009) plus an additional assessment of the background system using the Social-Hot-Spot database is performed. Finally an economic Life-Cycle-Cost Assessment (LCC) is applied to complete the triple bottom line. This LCSA-Model of the fermentation has been assessed for over 20 Scenarios with varying parameters for the interdependent processes to identify the most sustainable production setting.

The results showed high impacts caused by handling of diluted waste streams and informed about the benefits of alternative media and improved purification for the following design steps. The integrated model showed benefits of a coupled process design together with direct interactions of LCA, SLCA and LCC at each stage of early design. Direct feedback through integrated modelling enabled identification of promising routes at each step of the iterative development. This integrated approach can and should be applied to product developments of various disciplines to assure that sustainable goals are met through sustainability driven decisions.

**((References))**

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