Increasing flexibility of feedstock use in biorefineries via modelling: producing a targeted set of oleochemicals from different quality grades tallow

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Biorefineries provide an important alternative for petroleum-based ones to reduce CO_2 emissions and increase the share of renewables in the production of chemicals and fuels. Next to vegetable oils, the European oleochemical industry uses animal-based fats, produced by rendering animal by-products not intended for human consumption, as renewable raw materials for the production of fatty acid derivatives. In Europe, over 1.5 million metric tonnes of so-called category 3 animal fat (tallow) are produced annually by industrial rendering, of which one third is used by the oleochemical industry. This production has been rather stable, but in the previous decades, raw tallow supply for the oleochemical industry has tightened due to the increased biofuel production from tallow (Biermann et al., 2021; Dale et al., 2008). Currently, high quality fatty acids are typically produced using only higher-grade tallow, while normal quality fatty acids are mostly produced using lower-grade tallow. As the availability of higher-grade tallow will probably not increase in the coming years, the European oleochemical industry needs to develop the ability to process a wider diversity of feedstocks of varying (lower) quality into high quality biochemicals.

When evaluatuing feedstocks for the production of certain oleochemicals, it is recommended to take into account both the economic and environmental sustainability in a cradle to gate perspective (Zhang & Jiang, 2017). The technological performance and economic feasibility for using a feedstock can be evaluated by a techno-economic assessment (TEA), while Life Cycle Assessment (LCA) is most often chosen as the preferred method for environmental sustainability assessment.(Chomkhamsri et al., 2011) In this study, a model based on process simulation, TEA and LCA is presented and applied as a tool to increase the flexibility of feedstock use for producing a targeted set of products in existing biorefineries. The presented approach aids decision making on feedstock selection and processing, accounting for techno-economic feasibility and performance and environmental sustainability. Most applications to improve operational flexibility for biorefineries have focused on strategic decisions, such as selecting production technologies or plant location, by using mixed integer linear programming (MILP) models (Gargalo et al., 2017). These studies usually focus on the design-phase of a biorefinery. To our knowledge, no studies have been presented for oleochemical applications that are based on process simulation to increase operational flexibility at the plant level. In general, studies on improving the operational flexibility of existing biorefineries are limited, while process systems engineering may provide interesting possibilities to increase operational flexibility without the need for large investments The ever-changing oleochemical feedstock market highlights the importance of developing such an approach for existing oleochemical processing plants.

Central in the presented approach is building an input-output inventory of the biorefinery for a selection of possible feedstocks. For this purpose, a mathematical modelling approach, similar to typical chemical engineering computing, is used to build a flowsheet model of the biorefinery. Based on the developed flowsheet, mathematical equations are elaborated to calculate the input-output inventories. In every process block, product yields, product composition, utility consumption, energy consumption, direct emissions and waste streams are quantified. The calculations in a process block are done by using industrial averages or by connecting to a mechanistic process model developed in the process simulator Aspen Plus® (Nachtergaele et al., 2021a; Nachtergaele et al., 2021b).

The modelling approach is applied to an oleochemical biorefinery in which fatty acids, glycerol and propylene glycol are produced from different quality grades tallow under changing feedstock prices. A simplified scheme of the system under study is given in Figure 1. The fraction of lower-grade tallow used for the production of normal quality fatty acids is represented by x (currently x is 100%). The fraction of lower-grade tallow used for the production of high quality fatty acids is represented by y (currently y is 0%).For both normal quality fatty acids and high quality fatty acids, 21 possible feedstock mixtures are evaluated, with x and y gradually increasing from 0 to 100% in steps of 5%. The optimal value for x and y is investigated for a varying price difference between lower-grade and higher-grade tallow.

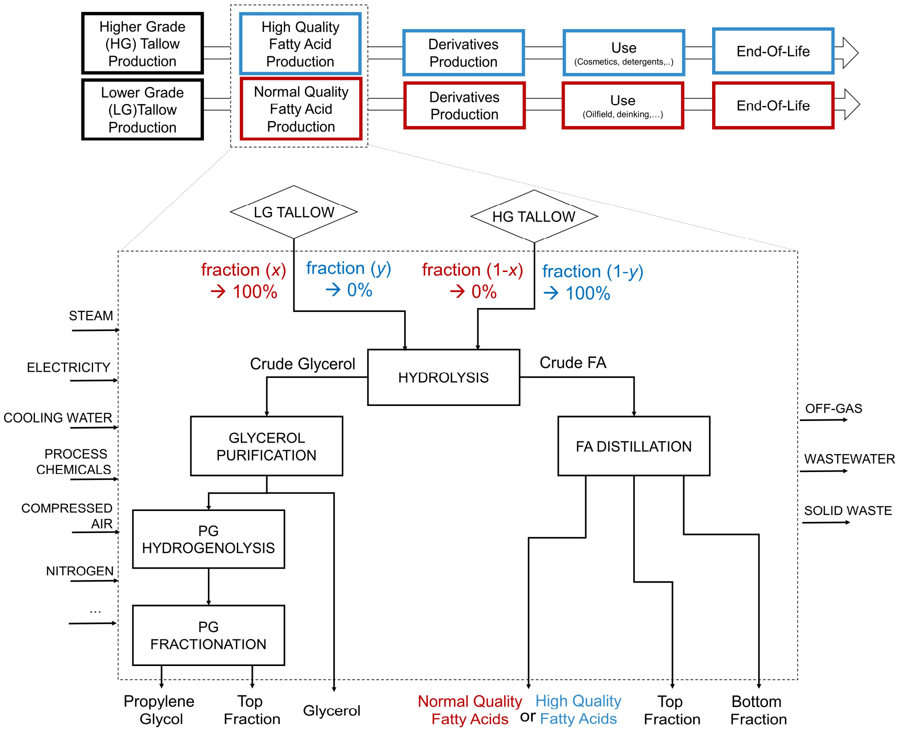

Figure 1. A simplified scheme of the system under study. During a campaign, either normal quality fatty acids (in red) or high quality fatty acids (in blue) are produced from either lower-grade tallow, higher-grade tallow or a mix.

This study shows that it is feasible to produce high quality fatty acids using lower quality grades tallow. However, in that case, the product yield in fatty acid distillation was reduced due to the higher reflux ratio in fatty acid distillation required to preserve the desired product quality. The study also shows that it is economically interesting to change the current operation and use lower-grade tallow instead of higher-grade tallow if the price difference between lower-grade tallow and higher-grade tallow is above a threshold of € 30 per tonne. In case of a price difference of €100/t, a switch results in an increase of the campaign's hourly operational profit by 40%. Due to the lower yield and higher heat duty, a switch to lower-grade tallow does result in an increase of the emissions per tonne fatty acids by approximately 6% and the resource use per tonne fatty acids by approximately 5%. These results are a crucial decision support tool for valuing, procuring and processing feedstocks in the oleochemical industry, allowing biorefineries to switch to other and lower quality feedstocks and increase their adaptability towards changes in demand and supply. In this respect, the challenge of its variable feedstock is truly becoming an opportunity for the oleochemical industry to be more adaptable towards future market changes and improve its overall sustainability

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