The sustainability problem in model biorefineries based on residues

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Conference topic: Biorefineries.

Abstract.
Biomass conversion has been profiled as one of the most important initiatives to mitigate the environmental damage caused by the excessive use of fossil fuels [1]. The comprehensive biomass conversion into a series of value-added products and energy vectors has been defined as the best way to take advantage of this renewable resource and overcome several techno-economic issues related to the stand-alone processing (i.e., minimizing waste streams and diversifying products portfolio) [2]. In this way, biorefineries can be perceived as a potential solution to implement a bioeconomy model and mitigate fossil fuels depletion. Despite several biorefineries configurations can be proposed to upgrade a biomass source, there is a select group of configurations with the highest sustainability and implementation potential. Indeed, different methodologies to assess the sustainability of a biorefinery have been reported in the open literature without a consensus about the way to measured it. Several authors have introduced different dimensions based on subjectivities. Then, there is an issue measuring the sustainability of a biorefinery or process [3–5]. Moreover, the sustainability should be understood as a way to identify potential weaknesses of a biomass upgrading process in early-design stages to minimize implementation risks. In this way, the research work has two objectives. The first objective is related to making a comprehensive review about the methodologies reported in the open literature to estimate the sustainability of biorefineries to elucidate advantages, disadvantages, and reproducibility. The second objective is to analyze the way to maximize the sustainability of five (5) biorefineries configurations estimating a global index based on technical, economic, environmental, and social indicators, finding the most influential dimensions.

The literature review was done making a comprehensive literature review considering only papers published between 2015 – 2023. The second objective was done estimating the sustainability index of five biorefineries addressed to upgrade (i) orange peel waste, (ii) avocado-processing residues, (iii) cassava-processing residues, (iv) carbon dioxide, and (v) rice-processing residues. A products portfolio addressed to produce different value-added products and energy vectors was proposed based on the conceptual design strategy reported by Moncada et al., [6]. The simulation of the proposed biorefineries was done using the Aspen Plus v.9.0 simulation software. Then, technical, economic, environmental, and social indicators were estimated based on the methodologies reported by Towler and Sinnot [7], ISO 14040 [8], and Eisfeldt et al., [9]. Software tools such as Aspen Process Economic Analyzer v9.0 and SimaPro v.8.3.0 were used to estimate the economic and environmental indicators. All the biorefineries were assessed in the Colombian context [10]. Once all the indicators were estimated, an optimization based on stochastic methods was proposed to find the weighting factors that maximize the sustainability. The optimization process was done using Python as free-code software.

The key results of the first objective allowed to elucidate the multicriteria decision analysis (MCDA), weighting factors method, and multi-objective optimization were the methodologies with most reports. Nevertheless, most of these methodologies are applied to only one or two study cases using different indicators and considerations. Thus, the reproducibility is a bottleneck of the proposed ways to assess the sustainability. On the other hand,

the five biorefinery scenarios showed different behavior based on the most impactful sustainability dimension. For instance, the orange-peel based biorefinery presented a high weighting factor in the environmental assessment to maximize the sustainability. Thus, this process can be proposed as an alternative to mitigate the environmental impact of orange juice producing factories without affecting cash flows and economic performance. On the contrary, the social dimensions have the lowest impact on the process sustainability. Therefore, this biorefinery should be strengthen in this dimension. Instead, the cassava biorefinery presented high economic performance rand the highest weighting factor. Then, this process has a high potential to be presented as a potential opportunity to business stakeholders. The other case studies were analyzed and the most influential dimensions were identified. In this regard, the sustainability assessment of biorefineries to identify strengths and bottlenecks. The proposed methodology can be applied to any process since the base is related to the mass and energy balances as well as the estimation of capital and operating expenditures.

Keywords: Biomass conversion, Biorefineries, Sustainability assessment, Stakeholders, Process Design.

Acknowledgements.
This paper is the result of the research work developed through the research project "Aprovechamiento y valorización sostenible de residuos sólidos orgánicos y su posible aplicación en biorrefinerías y tecnologías de residuos a energía en el departamento de Sucre" code BPIN 2020000100189.

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