Defining small-scale biorefineries based on a multi-factorial statistical typology

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Abstract:

The concept of biorefinery is one of the pillars of the bioeconomy, which promotes the diversification of transformation paths of bioresources. It is in fact defined as the sustainable conversion of biomass into a multiple bio-based products. In that, it is a broad concept that encompasses a multitude of technologies, modalities and scales. Generally, the scale of a biorefinery is brought to its processing or production capacities. Other attempts linked the scale of a biorefinery to its economic viability. However, to distinguish small-scale biorefineries (SSB) from the large one remain challenging. In this paper, we propose a definition of the SSB based on a multi-factorial analysis using statistical approaches. The methodological approach consisted of collecting data on 15 operational biorefineries as case studies, the selection of the variables (investment cost, processing capacity, process complexity, mobility of the process, biomass type and added value) and their statistical analysis using factorial analysis of mixed data (FAMD) and hierarchical ascending clustering (HAC). It resulted in the clustering of biorefineries generating four clusters: The smallest scale, the small scale, the hybrid and the large scale. From that, we extracted that the small scale can be defined by a small investment cost (less than 2M€), a small processing capacity (less than 100t/day), with a low process complexity able to produce from low to high added value products. The mobility of the facilities is also a crucial element in defining the small scale, since it ensure the proximity to biomass providers, but built-on site plants respecting the above characteristics can be small-scale as well. In addition, we found that the scale of a biorefinery depend on a trade-off between the mobility, the process and the socio-economic context. This equilibrium is necessary for the biorefinery economic and sustainable viability. It is even more essential in the case of small-scale biorefineries, to encounter the effects of not benefitting from the economy of scale.

Aim and approach used:

The aim of this work is to define the concept of a small-scale a biorefinery based on statistical analysis of existing biorefineries. In this work, we introduce an approach that identifies different-scale based designs of biorefineries, by clustering the biorefineries according to the various factors that define them: feedstock, process, economy and mobility of the facility.

In a first step, case studies of biorefineries auto-defining as small scale or farm scale were collected from various websites and biorefinery platforms. The focus was mainly on biorefineries that processed lignocellulosic biomass, or wood waste, and produced biomaterials and biochemicals. Energy and fuel producing biorefineries, which are usually regarded as large scale, were added to the list for representation purposes. 15 operational case studies were selected based on two principles: no missing data and a coverage of distinct variables. The selected variables were based on the literature and on expert-opinion: Processing capacity, investment cost, mobility of the biorefinery, process complexity, added value, and biomass type.

Initially, the dataset collected was subject to an analysis by two variables: Processing capacity and Investment Cost. It resulted in a non-discriminative dispersion, which showed that the two factors were not enough to dissect a tendency between scales. To that effect, the dataset was recoded to fit for clustering analysis. A combination of multifactorial data analysis and hierarchical clustering analysis were applied to, respectively, visualize the similarities between individuals and study their proximities and relevance (Pagès, 2004), and to build a hierarchy of clusters by merging pairs of clusters as the hierarchy moves up.

Scientific innovation and relevance:

The hypothesis made for this work is that the scale of biorefineries can be outlined by studying existing biorefineries, and analyzing the various factors that define them. It was based on the fact that, in the literature, there were no objective criteria that discriminated the large from the small scale biorefineries (Aristizábal-Marulanda and Cardona Alzate, 2019). Generally, when the scale is brought up, it is linked to the production or processing volume (Serna Loaiza et al., 2017). An attempt of defining the scale adopted the economic viability as the single criterion to define the *Minimum Processing Scale for the Economic Feasibility* (Serna-Loaiza et al., 2019).

However, biorefineries are complex entities that intertwine several elements in their constitution: different feedstock, types of processes, different products and uses, etc. (Cherubini et al., 2009). In addition to the technological features, biorefineries depend on the surrounding socio-economic and environmental context, which underlines that defining a scale-based design for biorefineries require taking into consideration all the potential characteristics.

In that sense, by this work, we intend to bring a potential response to defining the scale-based design of biorefineries based on core aspects, and distinguishing by that, the small-scale biorefineries from the large ones.

Results and conclusions:

The statistical analysis of the factors defining the case studies resulted in four clusters identified as: smallest scale, small scale, hybrid and large scale biorefineries. This distinction came out of the variable rates and modalities of the investment cost, the processing capacity, the mobility of the biorefinery, the process complexity and the added value. These factors not only identified the scale-based designs of biorefineries, but they revealed that a trade-off is crucial between these factors, in order for biorefineries to sustain and be viable. The following figure (Fig.1) represents the radar chart of the scale-based biorefineries based on the factors that define them.

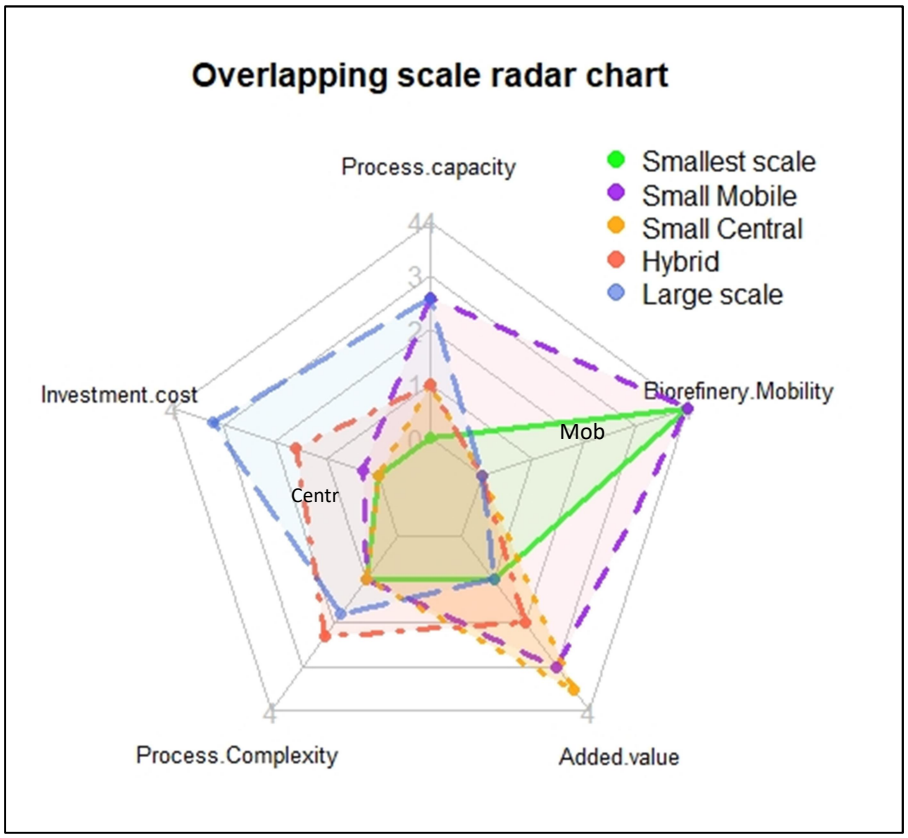

Fig.1 Radar charts of the biorefinery scale-based design classes. Note that Biorefinery Mobility has only two qualitative modalities: “Mob”, for mobile, and “Centr” for centralized.

References:

Aristizábal-Marulanda, V., Cardona Alzate, C.A., 2019. Methods for designing and assessing biorefineries: Review. Biofuels, Bioprod. Biorefining 13, 789–808. https://doi.org/10.1002/bbb.1961

Cherubini, F., Jungmeier, G., Wellisch, M., Willke, T., Skiadas, I., Van Ree, R., de Jong, E., 2009. Toward a common classification approach for biorefinery systems. Biofuels, Bioprod. Biorefining 3, 534–546. https://doi.org/10.1002/bbb.172

Pagès, J., 2004. Analyse factorielle de données mixtes, in: Revue de Statistique Appliquée. pp. 93–111.

Serna-Loaiza, S., García-Velásquez, C.A., Cardona, C.A., 2019. Strategy for the selection of the minimum processing scale for the economic feasibility of biorefineries. Biofuels, Bioprod. Biorefining 13, 107–119. https://doi.org/10.1002/bbb.1941

Serna Loaiza, S., Aroca, G.E., Cardona, C.A., 2017. Small-Scale Biorefineries : Future and Perspectives, in: Torres, I. (Ed.), Biorefineries Concepts, Advancements and Research. Nova Science Publishers, Inc. New York, pp. 39–72.