Sustainability analysis of biorefineries based on country socio-economic and environmental context.

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The sustainability concept involves the holistic analysis of different dimensions to identify impacts associated with implementing a biorefinery. The sustainability assessment of biorefineries involves three dimensions related to economics, environment, and society. Several approaches involving the estimation of individual indicators and impact categories have been developed to analyze these dimensions (Bello et al., 2020). Nevertheless, the evaluation of the social impact of biorefineries still is under development due to the lack of quantitative indicators. One of the most common approaches to carrying out a sustainability assessment is the life cycle thinking approach. Those analyses combining the life cycle thinking methodology and the three dimensions of sustainability are known as life cycle sustainability assessment (LCSA). In this way, the evaluation of the economic, environmental, and social dimensions is done applying the life cycle costing (LCC), environmental life cycle assessment (E-LCA), and social life cycle assessment (S-LCA) approaches. The individual analysis of the three dimensions of sustainability is another way to evaluate the sustainability of a biorefinery. The individual evaluation of the three dimensions of sustainability has been reported using different methodologies to evaluate them. The methodologies described are sometimes ambiguous and inconsistent, which decreases the understanding, reproducibility, and impact of the sustainability assessment (Mahbub et al., 2019). The lack of contextualized information (e.g., taxes, fuel costs, fertilizers, labor conditions) difficult the comparison the results reported by different authors. Issues related to the integral and equal evaluation of the three dimensions of sustainability have been identified (Costa et al., 2019). One of the main problems in performing and comparing different studies is based on the lack of a methodological guideline and a framework to perform a sustainability assessment. Therefore, this paper has two objectives. The first objective is to present a strategy to estimate the sustainability index considering an integral analysis of economic, environmental, and social information based on a specific country context. The second objective is to apply the proposed strategy to calculate the sustainability index of two biorefineries in emerging industrial and industrialized countries using the same feedstock. The purpose of this comparison is to elucidate how the sustainability assessment of biorefineries are influenced by the context where these facilities will be implemented.

The proposed strategy to estimate the sustainability index of biorefineries based on the context resulted from a literature review of different ways to assess the sustainability of biorefineries. This literature review was done searching information in different databases such as Scopus, Web of Science, and Sciencedirect. The step-by-step of the strategy include **(i)** a comprehensive understanding of the country involving aspects such as potential biomass sources, industrialization level, logistic performance, and competitive industrial performance, **(ii)** biomass upgrading strengths, market, and projections, **(iii)** macro socio-economic and environmental context for the development of biorefineries, **(iv)** proposal of biorefinery scenarios based on conceptual design, **(v)** life cycle assessment considering economic, environmental, and social perspectives involving all the production stages before biomass biorefining, **(vi)** normalization and weighting of each sustainability dimension considering **(vii)** optimization of the sustainability index estimated as the weighted value of the three dimensions, and **(viii)** sensitivity analysis to cover the entire spectrum of options that make the proposed biorefinery designs more or less sustainable. The sustainability index is presented in a ternary diagram to represent how to understand the analysis results easily. The study cases analyzed are focused on the upgrading of two types of biomass sources **(i)** lignocellulosic raw materials and **(ii)** agro-industrial residue produced in Colombia and Italy (i.e., an emerging industrial country and industrialized country). Biorefineries based on these raw materials were proposed. The products portfolio from each raw material change according to the country context. The biorefineries were simulated using the Aspen Plus v9.0 software. The processing scale of each biorefinery was defined according to the national production of each residue. First, the life cycle assessment methodology considered economical, environmental, and social information. Then, the four stages proposed by ISO 14040 were done considering a cradle to gate approach.

The results related to the specific country conditions of Colombia and Italy to implement biorefineries according to steps 1 to 3 are presented in tables 1 – 3.

Table 1. Logistic, Competitiveness, and Biorefineries presence selected countries.

Country	Bioref.	LPI	CIP	3I	Exports strength	Country classification
Colombia	5	2.81	0.032	0.296	Resource based manufactures	Emerging Industrial
Italy	31	3.73	0.244	0.479	Medium Technology manufactures	Industrialized
World Average	N.A.	2.86	0.067	0.323	N.A.	N.A.

*LPI: Logistic Performance Index, CIP: Competitive Industrial Performance, 3I: Industrial intensity

Table 2. Potential lignocellulosic biomass sources in Italy and Colombia.

Country	Crop	2G-Biomass	Production rate (Mt/y)*	Current uses
Italy	Wheat	Straw	10.4	Electricity, Heating, Composting, Biogas
	Rice	Husk and Straw	0.8	Not reported.
Colombia	Oil palm	OPF, EFB	13.0	Heating, Nutrients source for soil
	Sugarcane	SCB	13.0	Industrial heating and power generation

Table 3. Macro socio-economic information of Italy and Italy.

Country	Unit	Italy	Colombia
Tax rate	(%)	24.0	27
Interest rate	(%)	0.0	12.1
M/L	N.A.	1.4	1.1
Gender pay gap	%	4.7	0.1
Unemployment rate	%	9.2	12.1
CPI**	N.A.	52	92

*M/L: Minimum to living wage ratio for a person, **CPI: Corruption perception index. N.A. Not Apply. *Data before COVID-19 pandemic.

The information given in Tables 1 – 3 allows elucidating the type of products able to be produced in Colombia and Italy. Indeed, Colombia is not ready to upgrade biomass sources into specialty, and fine biochemicals since industrialization and logistic performance are not the best compared to the world average. In contrast, Italy can produce different products from biomass sources. After comparing these countries, the development, simulation, and analysis of the proposed biorefineries high values of the sustainability index were obtained for Italy compared to Colombia. Nevertheless, small-scale biorefinery applications are mote sustainable in Colombia since this country is still under development.

Conclusions.

Several authors have studied the sustainability assessment of biorefineries. Nevertheless, context-based analysis is required to understand the real implementation of biorefineries as greenfield or brownfield processes. The proposed strategy allows elucidating the sustainability index involving macro socio-economic data and conceptual design tools. This effort is to increase the reliability of the biomass upgrading designs.

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