Integration of the sustainability analysis and planetary boundaries assessment: Application in residues valorization.

Juan Felipe Hernández-Arango, Juan Camilo Solarte-Toro, Mariana Ortiz-Sanchez, Carlos Ariel Cardona Alzate.

Universidad Nacional de Colombia sede Manizales, Instituto de Biotecnología y Agroindustria, Departamento de Ingeniería Química, Km 07 vía al Magdalena, Manizales, Colombia.

***Corresponding author:** ccardonaal@unal.edu.co

Presenting author: Juan Camilo Solarte-Toro, jcsolartet@unal.edu.co

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Abstract.
The current environmental crisis caused by the excessive use of fossil fuels has encourage different efforts to measure and mitigate the current contribution of the anthropogenic activities on the earth's future. These efforts have been done at different levels (e.g., academia, industry, and government). Examples of the efforts done to mitigate and quantify the current damage are the proposal of the Sustainable Development Goals (SDGs) and Planetary boundaries. These efforts have been improved and changed since our world is dynamic and the worldwide geopolitical context is changing constantly. Even so, the planetary boundaries have been proposed as a way to measure how much a conversion process contributes to environmental damage. The planetary boundaries are: (i) climate change, (ii) biosphere integrity, (iii) land-system change, (iv) freshwater change, (v) biogeochemical flows, (vi) ocean acidification, (vii) atmospheric aerosol loading, and (viii) ozone depletion. Several of these limits have been overcome. Thus, strategies to reduce and maintain the status quo of the world are required. Indeed, an overcome of these limits can have serious damage on the earth's life. Biorefineries have been proposed as facilities to upgrade biomass and produce value-added products and energy vectors in a sustainable way. These facilities can contribute to mitigate and reduce the environmental impact of current industrial practices. Biorefineries must be sustainable by definition since a perfect balance between technical, economic, environmental, and social aspects must be guaranteed. Several authors have related the biorefinery concept with the accomplishment of the Sustainable Development Goals (SDGs). Nevertheless, few research efforts have been done to link the biorefinery concept and the planetary boundaries. In this way, this research work is addressed to quantify the impact of the implementation of a biorefinery in the planetary boundaries. Specifically, this research is focusedon determining the potential contribution to the planetary boundaries the implementation of second-generationbiorefineries.

Corn stover has been selected as raw material since this lignocellulosic residue can be found elsewhere in the world. This raw material was upgraded into a series of value-added products such as xylitol. The biorefinery was designed based on the conceptual design methodology reported by Moncada et al., [1]. The simulation of the biorefinery addressed to produce different value-added products was performed using the Aspen Plus v9.0 software. Then, an economic and environmental assessment was done to elucidate the best biorefinery configuration to upgrade corn stover. The economic assessment was performed considering the methodology reported by Towler and Sinnott [3]. Then, operational and capital expenditures were calculated, as well as, the net present value (NPV) of the biorefineries. On the other hand, the LCA methodology was used to elucidate the environmental impact of the biorefinery [4]. Finally, a translation of the LCA results to planetary boundaries was done considering different allocation factors (i.e., population and economic criteria). Five scenarios were assessed: (i) 100% mulching, (ii) 70% mulching, and 30% biorefinery, (iii) 50% mulching and 50% biorefinery, (iv) 30% mulching, and 70% biorefinery, and (v) 100% biorefinery.

The results obtained from an LCA were evaluated within the framework of planetary boundaries through the use of characterization factors, which are models that allow predicting the impact that an activity will have

based on the metrics resulting from a life cycle analysis in terms of planetary boundaries. The use of these factors also demands that the LCA results be expressed as a function of time, assuming that the activity will have the same impact on a continuous and sustained way, this allows the evaluation of planetary boundaries considering the temporal dimension, this type of analysis is called PB-LCA. In this methodology, the emissions inventory can be translated into the impacts they have on the Earth system based on the variables that define the planetary boundaries.

The most relevant results are addressed to elucidate the potential relation between the biorefinery and the planetary boundaries. The implementation of a biorefinery scheme to convert corn stover into xylitol increases the risk in the planetary boundaries such as Biochemical Flows and Climate Change. The "best" way to avoid affect the planetary boundaries is not valorize the corn stover (see **Figures 1A**). Nevertheless, this option is not suitable since other needs must be solved such as energy and productive transition. The implementation of a biorefinery increases the risk in the planetary boundaries (see **Figure 1B**). On the other hand, the allocation criteria have a high influence to take decisions since the use of the global population criteria seems to not affect the current planetary boundaries. Meanwhile, the use of economic allocations and country population-based allocations increases the risk to high levels. Therefore, a careful selection of the allocation factor must be done to assess the planetary boundaries of a process.

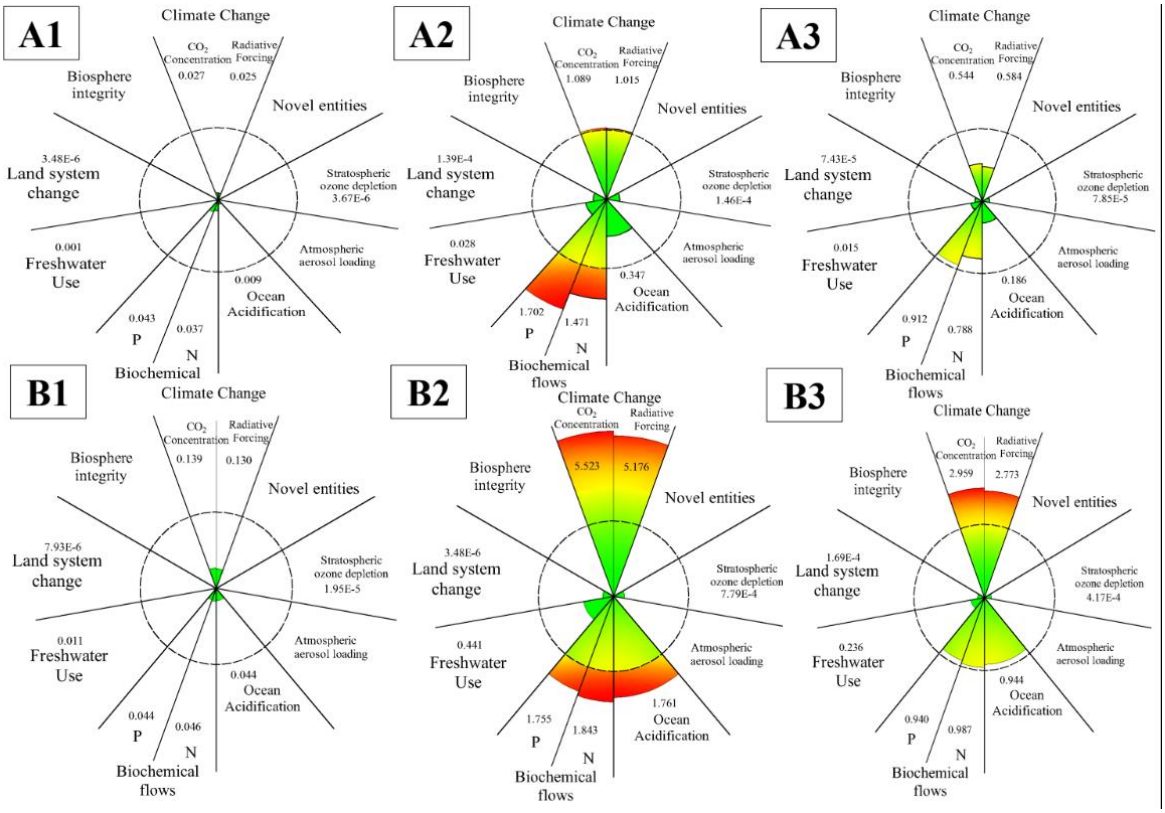

Figure 1. Planetary boundaries results: Comparison between the use of corn stover to mulching and xylitol production.

As conclusions, the estimation of the PB of a process is another perspective to analysis the impact of a process in a specific area. Nevertheless, the allocation factors and risk levels must be carefully defined to avoid misunderstandings. On the other hand, the implementation of biorefineries cause an "apparent" increase in the planetary boundaries' assessment. Nevertheless, the entire life cycle assessment must be done to consider the mitigation of the carbon dioxide emissions related to the replacement of an oil-based produce with a bio-based product. Therefore, more research and development are required related to the global analysis of the benefits

of implementing processes to upgrade biomass.

Keywords: Biomass conversion, Biorefineries, Sustainability assessment, Planetary boundaries, Waste biomass.

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