Integral economic, environmental, and social analysis of an avocado-based biorefinery in the Colombian context.

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Extended Abstract.
Biomass has been proposed as one of the most important alternatives to mitigate the environmental damage caused by the excessive use of fossil fuels. Thus, different biomass upgrading processes have been proposed to obtain different value-added products and energy vectors. Moreover, the integral use of the main biomass components is studied under the biorefinery concept as a way to replace most of the products obtained in a conventional oil refinery. Thus, these biomass-upgrading processes ought to be evaluated considering technical, economic, environmental, and social aspects under a sustainability framework. Nevertheless, this comprehensive analysis has not been performed in most of the cases, which limits to estimate the real impact of the implementation of these types of processes in developing and developed countries (Palmeros Parada et al., 2017). Indeed, most of the publications addressed to evaluate the biomass suitability to obtain different products through any process or technology have been evaluated only considering economic and environmental features leaving aside social aspects. In this way, this work aims to perform a comprehensive evaluation of an avocado-based biorefinery in the Colombian context considering economic, environmental, social aspects to elucidate the performance of the proposed biorefinery as well as identify the way to evaluate a biomass-upgrading process in terms of interdimensional indicators (e.g., socio-economic, eco-efficiency, and socio-ecology).

The methodology applied to accomplish the objective of this work considered the following stages: **(i)** Conceptual design of an avocado-based biorefinery considering marketable products in the Colombian context. **(ii)** Simulation of the proposed biorefinery using the Aspen Plus v9.0 simulation tool to obtain the mass and energy balances of the process. **(iii)** Economic evaluation of the biorefinery using the Aspen Process Economic Analyzer (APEA) software to estimate the capital and operational expenditures of the process as well as to evaluate the economic performance of the process in terms of economic metrics such as net present value, internal rate of return, and payback period. **(iv)** A cradle to gate environmental analysis applying the life cycle assessment (LCA) methodology. **(v)** A social evaluation of the main implications of the proposed biorefinery considering the stakeholder, categories, subcategories, and impact indicators stablished by the Product Social Life Cycle Assessment database developed by GreenDelta.

The ***first stage*** (i.e., conceptual design of the biorefinery) was done considering the Montes de Maria region as a case of study due to the socio-economic detriment suffered due to the Colombian armed conflict in recent years (Acevedo Navas, 2012). In this way, the proposed biorefinery can be seen as an alternative to evaluate the potential of the avocado crop in this region as well as serve to identify some entrepreneurship alternatives. The products of the proposed biorefinery (i.e., avocado seed oil, electricity, guacamole, and biogas). The block diagram of the proposed biorefinery is presented in Figure 1. The ***second stage*** (i.e., simulation of the biorefinery) was done using the Aspen Plus simulation tool. The NTRL-RK thermodynamic method was selected to calculate the fugacity and activity coefficients of the components in gas and liquid phase. Moreover, a mass flow rate of raw material (i.e., avocado) of 10 tonnes per day was proposed considering the avocado production of the Montes de Maria region. Finally, the simulation of the proposed biorefinery was complemented using experimental data reported in the open literature (Solarte-toro et al., 2019). The ***third and four stages*** (i.e., economic and environmental evaluations) were done using the APEA and SimaPro software, respectively. For the third stage, the mass and energy balances obtained from the second stage were used to perform the sizing of the equipment in the biorefinery. On the other hand, the cost of the raw materials, reagents, utilities and labor was considered into the economic evaluation. The straight-line depreciation method was used as well as an operation time of 8000 hours per year. Finally, the tax rate and interest rate used to perform the economic calculations was 17% and 25%, respectively (Serna-Loaiza et al., 2018). Regarding to the fourth stage, the environmental analysis was done following the life cycle assessment methodology. For this, a cradle to gate analysis is considered. The functional unit used to perform the analysis was 1 kg of product. The life cycle inventory as well as the mass and energy balances of the process were used as input data to perform the environmental life cycle assessment (García et al., 2017). Finally, the ***fifth stage*** (i.e., social

analysis) was done considering workers and local community as stakeholder. Then, indicators such as fair salary, children in employment, living wage, natural withdrawal, and carbo dioxide emissions (Eisfeldt and Ciroth, 2018).

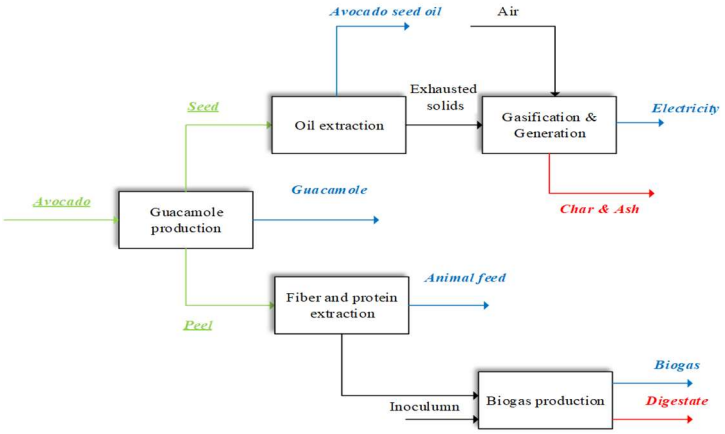

Figure 1. Block diagram of the propose avocado based biorefinery in the Montes de Maria region, Colombia.

The results are analyzed considering the economic, environmental, and social perspective. The economic assessment of the biorefinery was unfeasible considering the proposed scale. Nevertheless, a sensitivity analysis of the processing scale showed that an increase of 125% of the base case improves the feasibility of the process. In fact, the net profit margin at this condition was 73 million of dollars. On the other hand, the payback period of the process was estimated in 4 years. Regarding the environmental analysis, the life cycle assessment shows that the high water consumption of the avocado crop is one of the most important hotspots of the process. Moreover, the social analysis demonstrated the high difficult of the farmers in the Montes de Maria region. The interdimensional analysis shows a proportional relation between the environmental and social analysis, meanwhile the economic analysis has an inverse relation respect to the other two aspects.

Conclusions.

The integral analysis of biorefineries allows elucidating the relation between the three pillars of sustainability (i.e., economic, environmental and social). In fact, the overall sustainability of a biorefinery should be accomplished establishing limits between the economic performance, the environmental impact expected and the social implications of the process. Thus, these limits should be considered in the conceptual design stage of the process.

References.

Acevedo Navas, C., 2012. Los Montes de María: Región, conflicto armado y desarrollo productivo. Amaranto Daniels Puello & Alfonso Múnera Cavadía. Memorias Rev. Digit. Hist. y Arqueol. desde el Caribe 9, 279–285.

Eisfeldt, F., Ciroth, A., 2018. PSILCA - A Product Social Impact Life Cycle Assessment database.

García, C.A., Morales, M., Quintero, J., Aroca, G., Cardona, C.A., 2017. Environmental assessment of hydrogen production based on Pinus patula plantations in Colombia. Energy 139, 606–616. https://doi.org/10.1016/j.energy.2017.08.012

Palmeros Parada, M., Osseweijer, P., Posada Duque, J.A., 2017. Sustainable biorefineries, an analysis of practices for incorporating sustainability in biorefinery design. Ind. Crops Prod. 106, 105–123. https://doi.org/10.1016/j.indcrop.2016.08.052

Serna-Loaiza, S., Carmona-Garcia, E., Cardona, C.A., 2018. Potential raw materials for biorefineries to ensure food security: The Cocoyam case. Ind. Crops Prod. 126, 92–102. https://doi.org/10.1016/j.indcrop.2018.10.005

Solarte-toro, J.C., Romero-garcía, J.M., Martínez-patiño, J.C., 2019. Acid pretreatment of lignocellulosic biomass for energy vectors production : A review focused on operational conditions and techno-economic assessment for bioethanol production. Renew. Sustain. Energy Rev. 0–1. https://doi.org/10.1016/j.rser.2019.02.024

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