Sustainability performance of biorefineries based on country socio-economic context and technical, economic, environmental, and social aspects

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PROGRAMA COLOMBIA CIENTÍFICA
RECONSTRUCCIÓN DEL TEJIDO SOCIAL EN ZONAS DE POSCONFLICTO EN COLOMBIA

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Research group in Chemical, Catalytic and Biotechnological Processes

Content

1. Introduction

Sustainability and Biorefineries design

Sustainability

It has been defined as the perfect balance between economic, environmental, and social aspects of a system or process overtime.

The Brundtland Report – Our Common Future, 1987

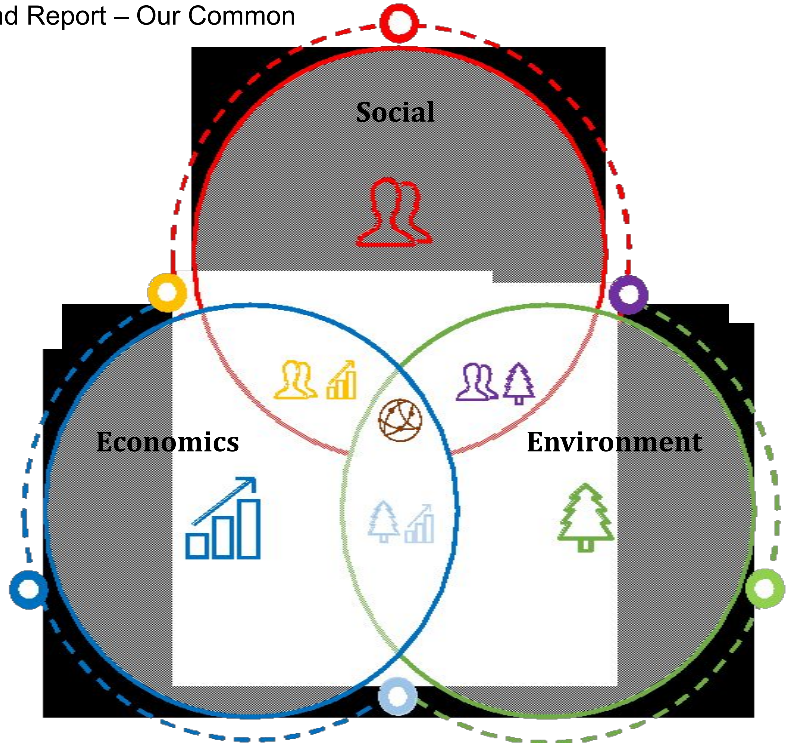

Figure 1. Sustainability Dimensions (Triple- Bottom Line)

Biorefineries Design

Biorefineries design must involve several aspects related to the specific-context where these facilities will be implemented.

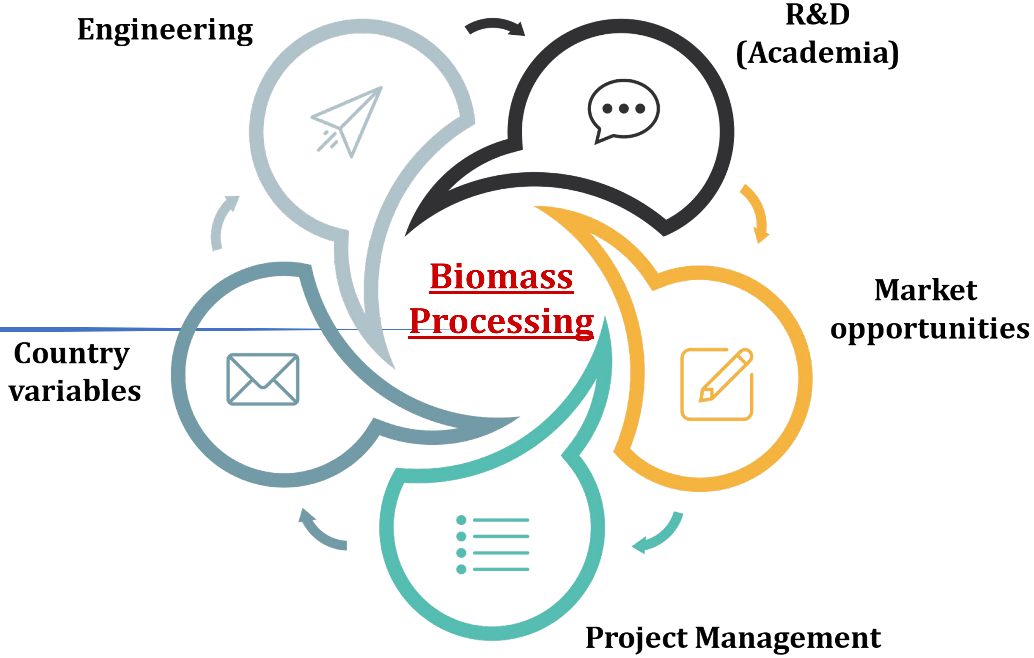

Figure 2. Key aspects for biorefineries design

Biomass Definition: All renewable resource able to be upgraded in any valuable product. Not only energy crops and 2G biomass.

1. Introduction

Assessment methodologies of sustainability dimensions

Economic

Assessment methodologies

- Quantitative Indicators (NPV, PBP) – based on Aspen Economic Analyzer
- Life cycle costing (LCC)
- Early-stage costing (Economic Potential)

Tools have been created to give costs estimations

aspentech

Aspen Economic Analyzer

Most biorefinery studies involve the economic dimensions assessment

Environmental

Assessment methodologies

- Environmental impact assessment (WAR GUI, GREENSCOPE)
- Environmental life cycle assessment (E-LCA)
- Carbon and Water footprints

Tools have been created to calculate the impact of a process or system

Most biorefinery studies involve the environmental dimension assessment

Social

Assessment methodologies

- Social life cycle assessment (S-LCA)
- Social impact assessment (SIA)
- Qualitative indicators
- Quantitative indicators

Tools are being created to make a more reliable social assessment

PSILCA

Few/Scarce biorefinery studies involve the social dimensions assessment

1. Introduction

Biorefineries design considerations related to specific country conditions

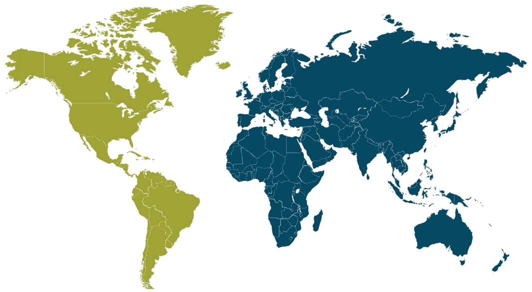

Figure 3. World Map

Table 1. Biomass sources per region

Region	2G biomass source
North America	Corn, Forest biomass
South America	Sugarcane, Rice, Palm
Europe	Wheat, Olive, Corn

Biomass use options

1. Biomass upgrading and valorization ***in situ*** in *Brownfield* and *Greenfield* processes
2. Biomass trade without any further valorization

Country variables to be considered

Logistic Performance Index (LPI), Competitiveness Industrial Performance (CIP), Industrial Intensity Index (3I), Taxes, Wages – **Indicators estimated by the UN**

For example:

↑ LPI, ↑ CIP, ↑ 3I:

1. Products can be composed of high-value added compounds
2. Biomass upgrading at large scale in existing plants
3. Possibilities to implement high-tech processes at different scales

↓ LPI, ↓ CIP, ↓ 3I:

1. Most biomass applications could be related to bioenergy production
2. Biomass upgrading at large scale in existing plants is scarce
3. Small-scale processes are more suitable to respond to regional needs

2. Research objective

This work aims to propose a sustainability assessment strategy of different biorefinery configurations using a comprehensive index based on technical, economic, environmental, and social information involving country-specific data.

3. Methodology

Ste-by-step to involve country variables in the assessment of biorefineries sustainability

Problem Identification → Process context → Country variables → Define scale and products

→ Dimensions assessment → Sustainability Index → Choose better alternative

The process should be economic feasible at the proposed scale

3. Methodology

Defining the sustainability index

$$SI = w_1 \sum Technical + w_2 \sum Economic + w_3 \sum Environmental + w_4 \sum Social$$

Sustainability weighting factors

Table 2. Weighting factors approach adapted from Life Cycle Initiative, 2020, UN

Approach	Description	Advantages	Disadvantages
Equal weighting	All factors have the same value	Simple and easy to apply	Neutrality
Robust indicators	Most robust factors have higher values	Robust indicators give the final result	Subjectivity.
Stakeholder values	Weights are defined	Stakeholders' opinions are involved.	Time-consuming.

Sustainability dimensions

Table 3. Indicators involved to estimate the Sustainability Index (SI) – Solarte-Toro, 2020, ESPR, DOI: 10.1007/s11356-022-20857-z

Dimension	Indicators	Symbol
Technical	Process Mass Intensity	PMI
	Renewability Index	RI
	Self-generation index	SGI
Economic	Payback Period	PBP
	Turnover ratio	TR
Environmental	Carbon Footprint	CF
	Water Footprint	WF
Social	Minimum to Living wage ratio	M/L

3. Methodology

Defining the sustainability index

Normalization approaches

Option 1 (Ruiz-Mercado, 2011)

$$\text{Indicator normalization} = \frac{\text{Actual} - \text{Worst}}{\text{Best} - \text{Worst}}$$

Best and Worst cases are defined depending on the indicator. Then, a **lower level of subjectivity is introduced and the comparison of the results is easier**

Option 2 (ISO 14040/44)

$$\text{Indicator normalization} = \frac{\text{Actual}}{\text{Normalization Value}}$$

Normalization value is defined by the user. Then, **a high level of subjectivity is introduced and the comparison of the results is more difficult**

Table 4. Range of values for each indicator

Dimension	Symbol	Best case	Worst case
Technical	PMI	1.0	50.0
	RI	1.0	0.0
	SGI	1.0	0.0
Economic	PBP[1]	0.1*Project lifetime	0,9*Project lifetime
Environmental	TR	4.0	0.2
	CF[2]	0.5	20.0
	WF[3]	1.0	20.0
Social	M/L	1.0	0.5

[1] Payback period is given in years

[2]Carbon footprint is given in kg CO_2-eq/kg of raw material

[3]Water footprint is given in m^3/kg of raw material

3. Methodology

Defining the sustainability index

Sustainability Index (SI) – Value range

Low SI	**Medium SI**	**High SI**
0 – 30%	30 – 80%	80 – 100%

Sustainability Index (SI) – Applications

1. Compare the sustainability of different biorefinery configurations in the same country
2. Compare the sustainability of the same biorefinery configuration in different regions/countries
3. Compare the sustainability of different facilities implemented in different countries

Case Study

Type of application: Application 1.

Step 1. Problem identification: Sub-use of avocados in rural zones and low farmer's incomes.

Step 2. Process context: Colombia □ Rural zones

Step 3. Country variables:

Table 5. Country variables

Item	LPI	CIP	3I
Colombia	2.94	0.032	0.296
World	3.64	0.067	0.323
% Deviation	-19.23	-52.23	-8.35

If the values of the country variables are lower than the average world values, **small-scale and low complex biorefineries** would be the best alternatives

3. Methodology

Case Study – Avocado-based biorefineries

Step 4. Define scale and products

Avocado
(*Persea Americana var Americana.*)

Rejected avocado in 2019*

2534 tons

Just for one small-region in the country (5 km^2)

20%

Biorefineries processing scale
420 ton/year (1.2 t/d)

Figure 3. First small-scale biorefinery – Small-AB1

Figure 4. Second small-scale biorefinery – Small-AB2

4. Results

Case Study – Avocado-based biorefineries

Step 5. Sustainability dimensions assessment – Economic feasibility estimation at the proposed scale

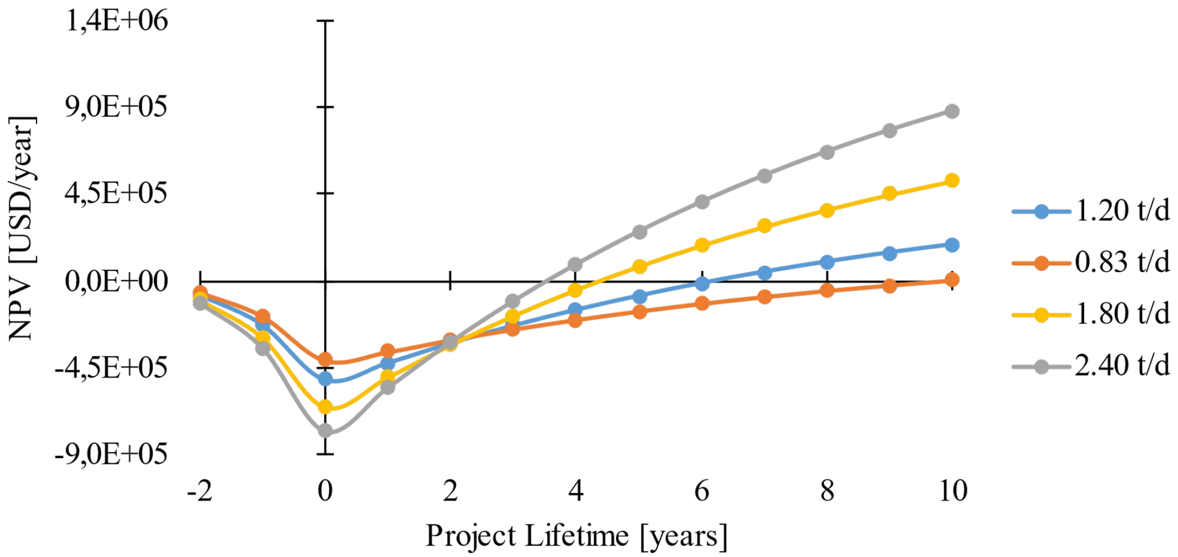

Figure 5. Biorefinery I – Small – AB1

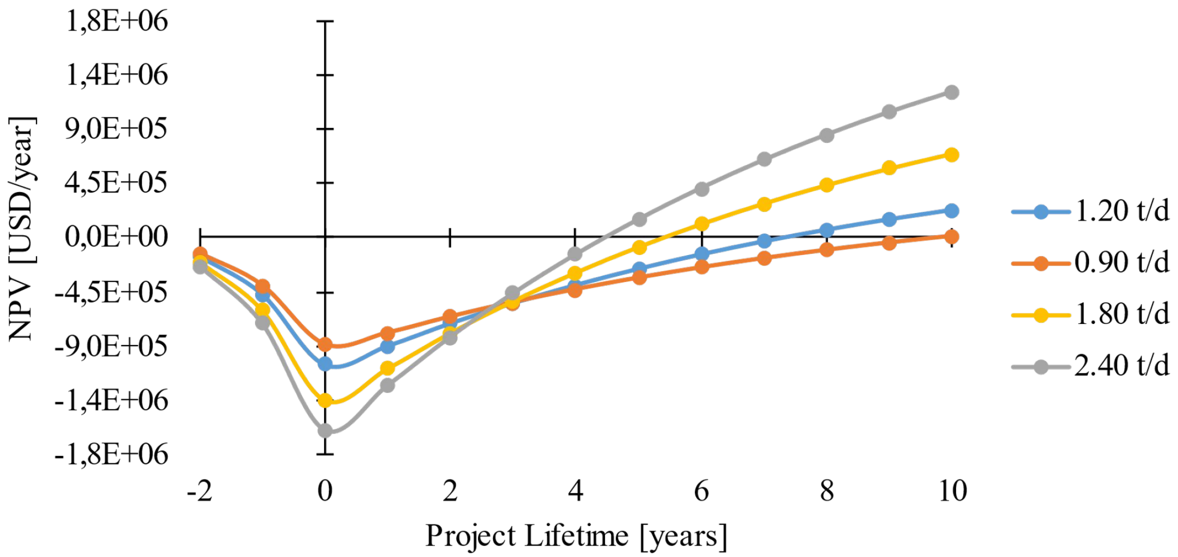

Figure 6. Biorefinery II – Small – AB2

Economic feasible at the proposed scale
MPSEF: 0.83 t/d

Economic feasible at the proposed scale
MPSEF: 0.90 t/d

4. Results

Case Study – Avocado-based biorefineries

Step 5. Sustainability dimensions assessment

Technical Dimension

Table 6. Mass and Energy indicators

Biorefinery	PMI (kg/kg)	Yield (kg/kg)	RI (%)	SGI (%)
I	3.89	0.26	100	21.25
II	1.46	0.68	100	61.89

Economic Dimension

Table 7. Value of investment indicators

Biorefinery	PBP (years)	TTR (1/years)
I	6.24	0.81
II	7.59	0.52

Environmental Dimension

Table 8. Environmental indicators

Biorefinery	CF (kg-CO_2/kg raw material)	WF (m^3/kg raw material)
I	8.99	6.66
II	0.77	1.38

Social Dimension

Table 9. Social indicators

Biorefinery	M/L	Max M/L
I	0.72	0.95
II	0.72	0.75

4. Results

Case Study – Avocado-based biorefineries

Step 5. Sustainability dimensions assessment

Technical Dimension

Table 6. Mass and Energy indicators – Normalized values

Biorefinery	PMI (kg/kg)	Yield (kg/kg)	RI (%)	SGI (%)
I	0.94	0.22	1.00	0.21
II	0.99	0.66	1.00	0.62

Economic Dimension

Table 7. Value of investment indicators – Normalized values

Biorefinery	PBP (years)	TTR (1/years)
I	0.35	0.16
II	0.18	0.08

Environmental Dimension

Table 8. Environmental indicators – Normalized values

Biorefinery	CF (kg-CO_2/kg raw material)	WF (m^3/kg raw material)
I	0.56	0.70
II	0.99	0.98

Social Dimension

Table 9. Social indicators – Normalized values

Biorefinery	M/L	Max M/L
I	0.44	0.90
II	0.44	0.50

4. Results

Case Study – Avocado-based biorefineries

Step 6. Index estimation

Equal weighting factors

Table 6. Sustainability Index

Biorefinery	SI (%)
I	53.74
II	60.04

Table 7. Scenarios for Sensitivity Analysis – Equal weighting

Analysis	Assessment
4D	TEAS
3D	TEA, TES, TAS, EAS
2D	TE, TA, TS, EA, ES, AS
1D	T, E, A, S

Table 7. Scenarios for Sensitivity Analysis – Equal weighting

Sensitivity analysis of the weighting factors

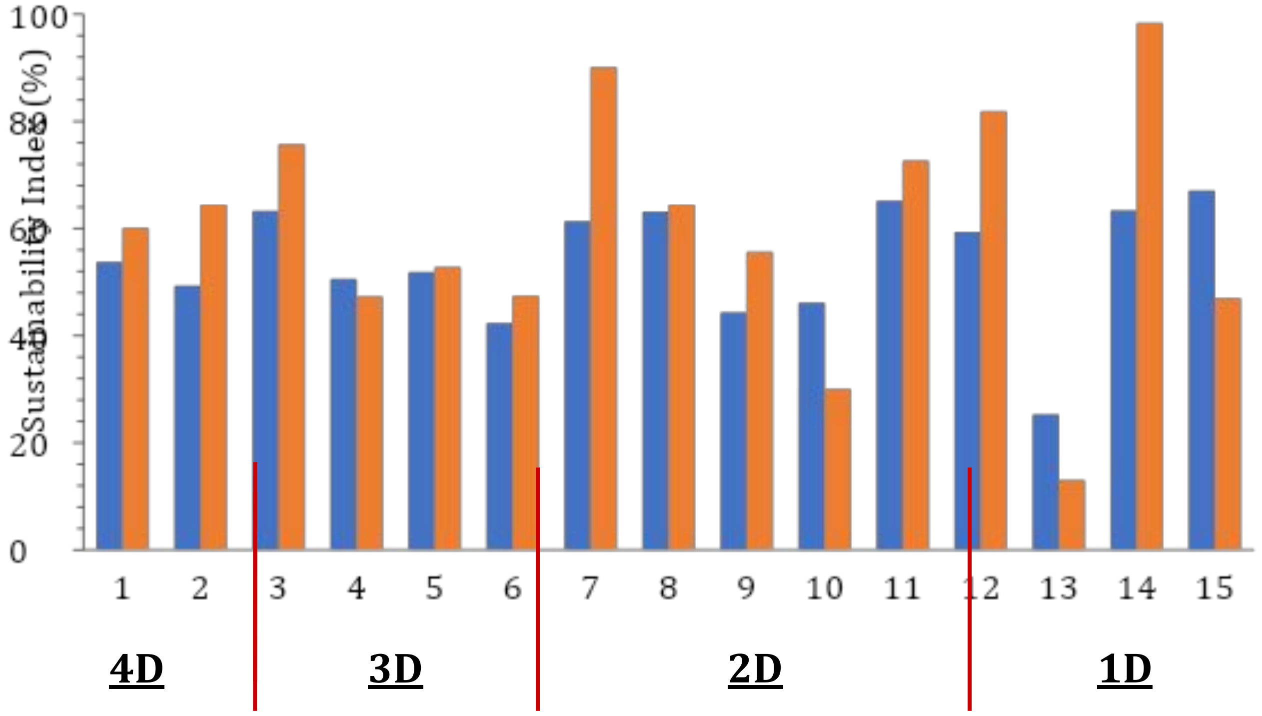

Figure 7. Sustainability Index change based on the assessment type

Step 7. Choose the best alternative: Scenario 2 – Small-AB2 (Guacamole) is the most sustainable option

5. Conclusions

- Specific country variables such as taxes, logistic performance, industrial competitiveness, and industrial intensity are key variables to be introduced into the biorefineries design and products portfolio definition.

- Estimating the sustainability index allows comparing different biorefinery configurations regardless of the plant location and process configuration.

- Regarding, the case study, the avocados upgrading to guacamole and biogas (to produce electricity) is the more sustainable option since the SI is higher in most of the equal weighting situations.

- To avoid the weighting problem the best alternative is to estimate all the possible values of the SI and show the results to the stakeholders and shareholders.

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Conocimiento Global para el Desarrollo

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Minciencias

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ICETEX
Invertimos en el talento de los colombianos

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