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Techno-economic and environmental assessment of biorefinery technologies

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Aim
The research aims to contribute in the development of a methodology to carry out the comparison of technical, economic and environmental assessment for the biochemical and thermochemical routes integrated in a sugarcane biorefinery context. This methodology represents a competitive advantage to identify opportunities for biorefinery processes aiming to support the gradual transition to a biobased economy in Brazil.

Methods
The first step to achieve this goal is represented by the conception and implementation of a multiple criteria approach (e.g. energetic, exergetic, economic and environmental) of sustainable biorefineries configurations. Afterwards, the application of computational tools to synthesizing and improve the processes efficiency looking for the valorization of sugarcane biorefinery residues focus on the bioethanol production and electricity generation. In the last phase a sensitivity analysis will be performed to analyze the robustness of the designs and identify possible improvements of the most promising sustainable technologies with respect to multiple performance indicators covering the following scenarios: ROUTE 1: Ethanol production (1G), Optimized autonomous distillery; ROUTE 2: Ethanol production (2G), Biochemical platform; ROUTE 3: Thermochemical platform.

Results
The results indicated sustainable settings/rankings of these production processes based on multi-criteria approach. In addition, the comparison for each selected technological route is presented through the assessment of thermodynamic, exergetic, economic and environmental performances by using the global energy and exergy efficiencies, capital investment (CAPEX) and operational expenses (OPEX), overall CO2 emissions and CO2 equivalent index (exergetic base), as comparison metrics.

Conclusion
Regarding to the the exergy efficiency of the processes, it is verified that the chemical reactions involved in the hydrolysis, fermentation and combustion steps represent the principal destroyed exergy in the bioethanol production and electricity generation using sugarcane bagasse and straw as an energy input. Regarding the biochemical route, the enzymatic hydrolysis, linked to the conventional process, allowed to reach the highest rate of ethanol production. However, the economic analysis has shown that this process has the highest capital cost. Lastly, the thermochemical route was the highest rate with reference to the surplus power generation, at the cost of the greatest environmental impact of the technological configurations.

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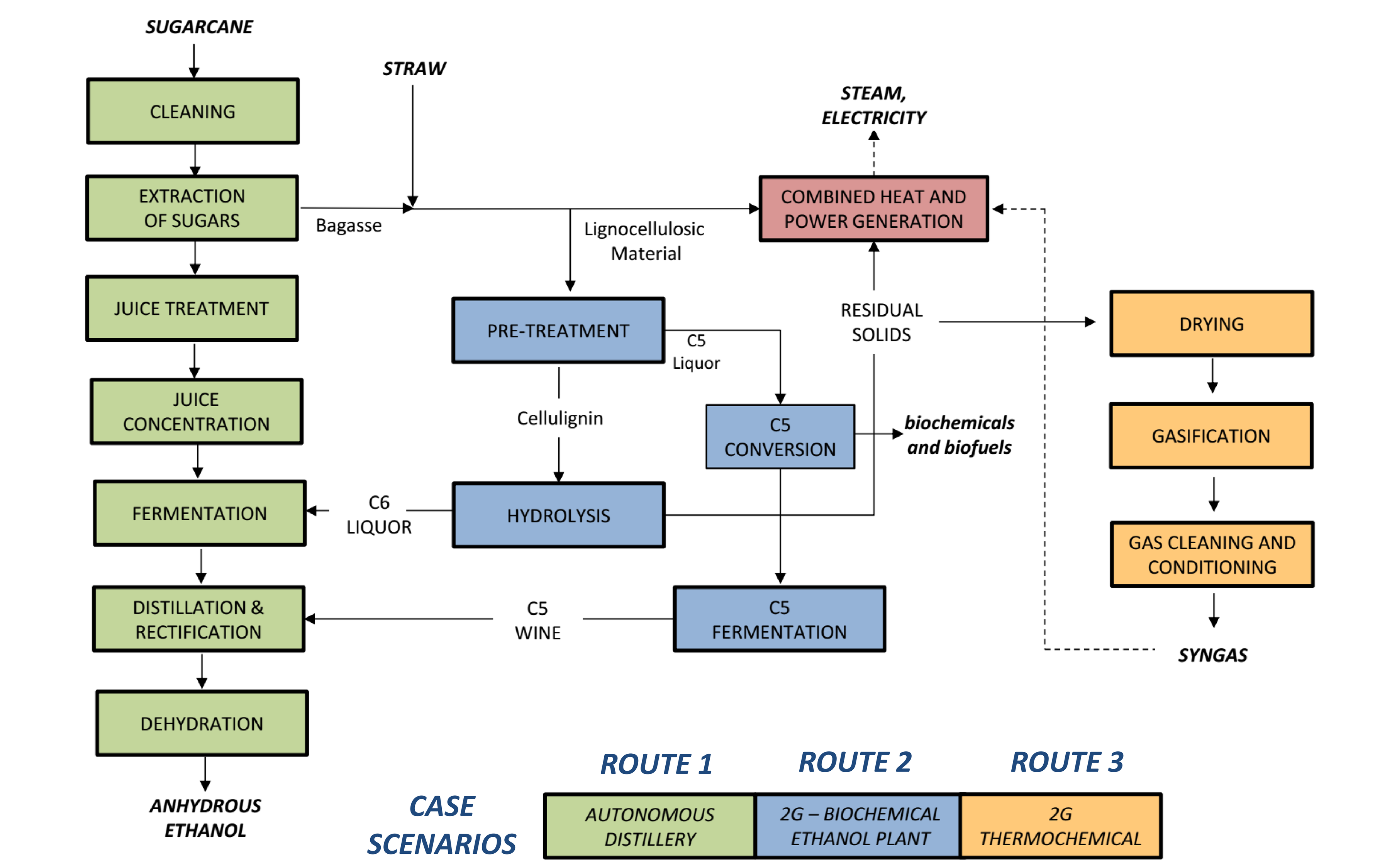
RESEARCH AIMS



SPECIFIC OBJECTIVES

- The conceptual design, modeling and assessment of biorefinery systems based on multiple criteria (**e.g.** *energetic, exergetic, economic and environmental*) for sustainable biorefineries configurations;
- Comparing the exergy performances of the technological routes evaluating alternatives to minimize entropy generation (irreversibility) in order to improve the quality of the products obtained.
- Identification of opportunities and selection of potential systems for the three selected technological routes based on qualitative comparisons of techno-economic and environmental performance like carbon efficiency, production costs and greenhouse gas (GHG) emissions.
- A sensitivity analysis performance to explore the robustness of the designs focusing on the valorization of sugarcane biorefineries for the bioethanol production and electricity generation inside a bio-based economy context.

METHODS

MAIN OPERATING CONDITIONS

Parameters	*Values*	*Units*
Bagasse	140	t/h
Milling (processed cane)	500	tc/h
Hours to harvest	5000	h/year
Moisture content of cane	50	(w/w)%
Exergy of sugar cane juice $_{\text{wet basis}}$	5614	kJ/kg
Exergy of bagasse $_{\text{wet basis}}$	9892	kJ/kg

(w/w)%: mass percent

KEY PERFORMANCE INDICATORS

Exergy efficiency

$$\eta_B = \frac{\sum B_{\text{products}}}{\sum B_{\text{inputs}}}$$

Irreversibility rate

$$I = \sum B_{\text{inputs}} - \sum B_{\text{products}}$$

Renewability exergy index

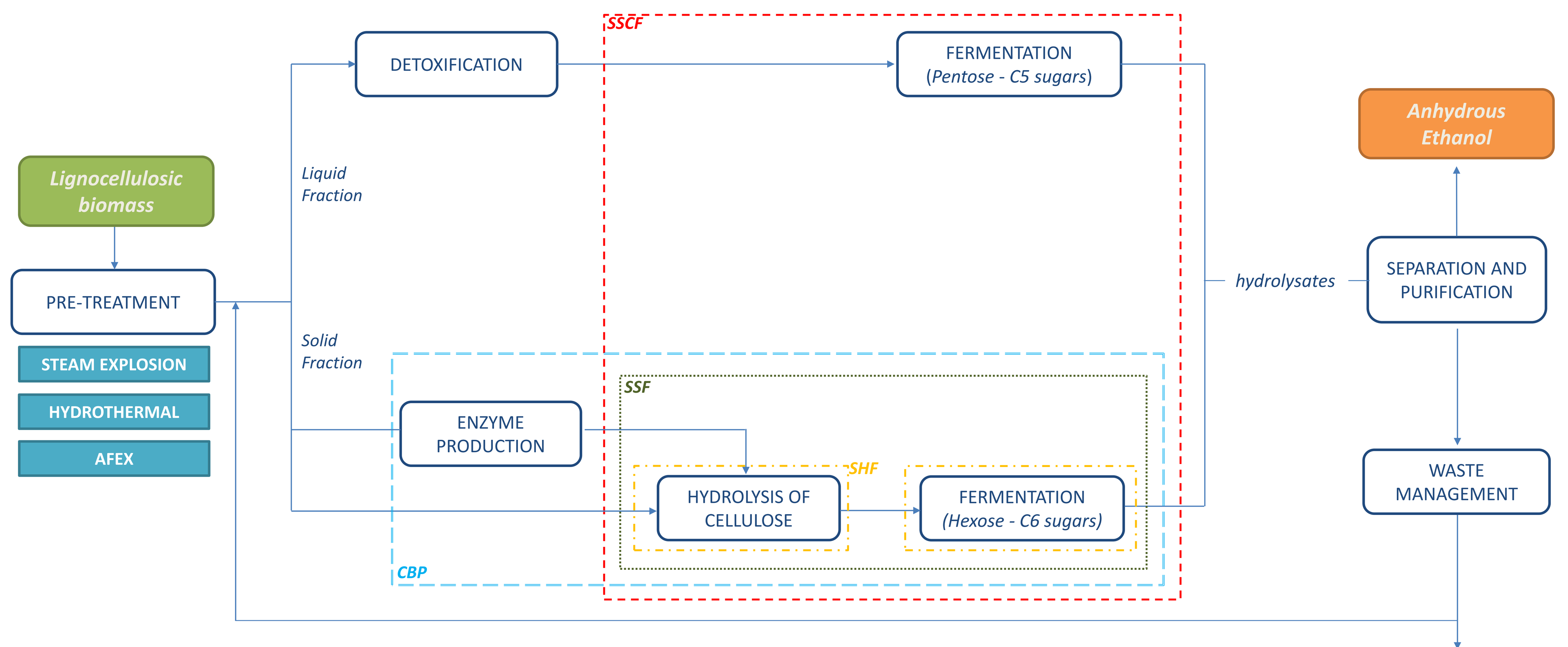
$$\lambda = \frac{\sum B_{\text{product}}}{B_{\text{fossil}} + B_{\text{destroyed}} + B_{\text{deactivation}} + B_{\text{disposal}} + \sum B_{\text{emissions}}}$$

CO_2 equivalent index in exergetic base

$$CO2\ eq.emissions = \frac{Estimate\ global\ CO2\ emissions}{Exergy\ of\ the\ products}$$

$0 \le \lambda < 1$ environmentally unfavorable
$\lambda = 1$ reversible process with non-renewable inputs
$\lambda > 1$ environmentally favorable
$\lambda \to \infty$ reversible process with renewable inputs

Biochemical route - Configurations of processes of bioethanol production from sugarcane



SHF Separate (or sequential) hydrolysis and fermentation
SSF Simultaneous saccharification and fermentation
SSCF Simultaneous saccharification and co-fermentation
CBP Consolidated bioprocessing

Combined 1st and 2nd Generation Bioethanol Production

SHF Process
(using 50 % of bagasse in the 2G process and steam explosion pretreatment)

Efficiencies (%)	
Energy efficiency	48.05
Exergy efficiency	38.78

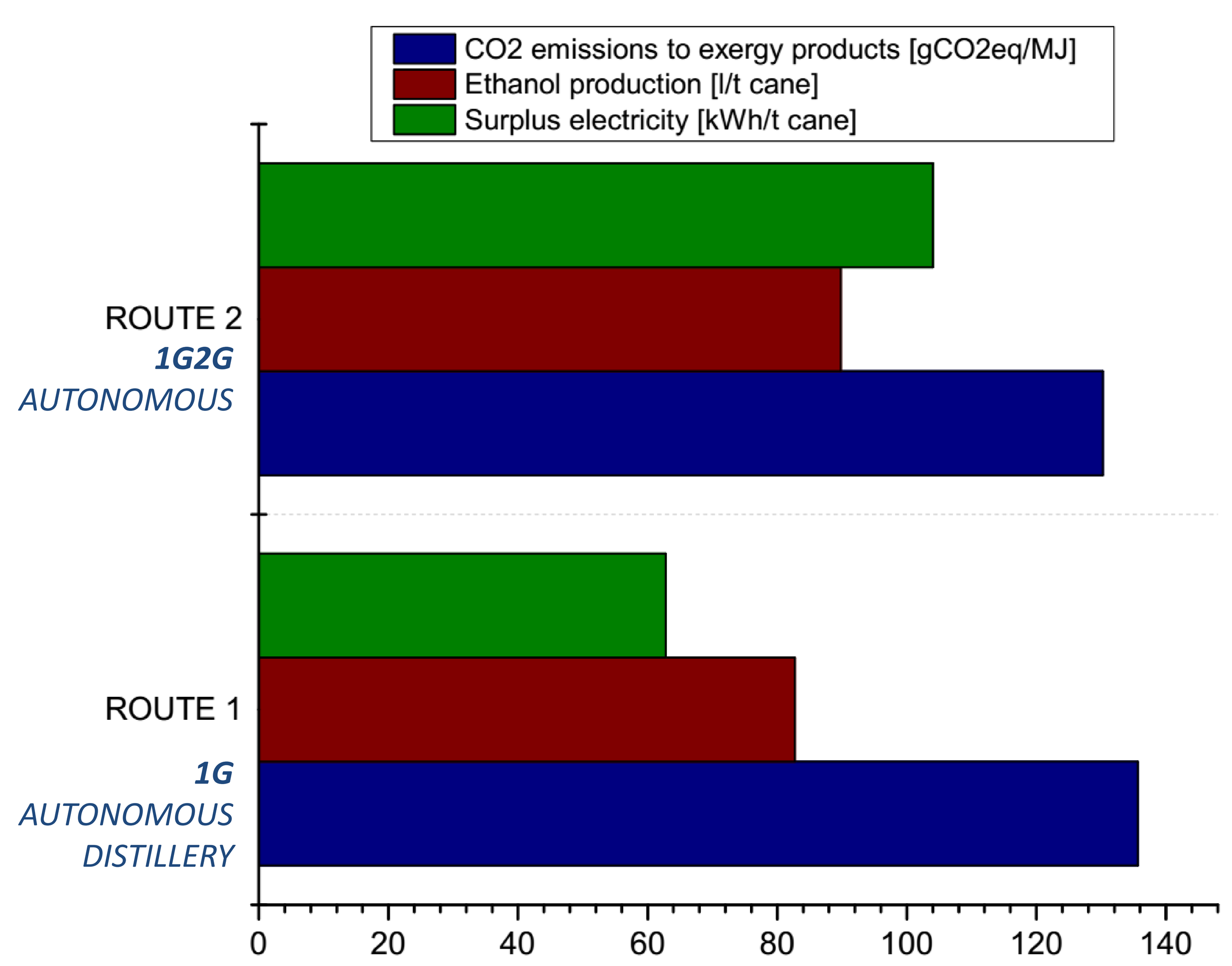
Streams Parameters

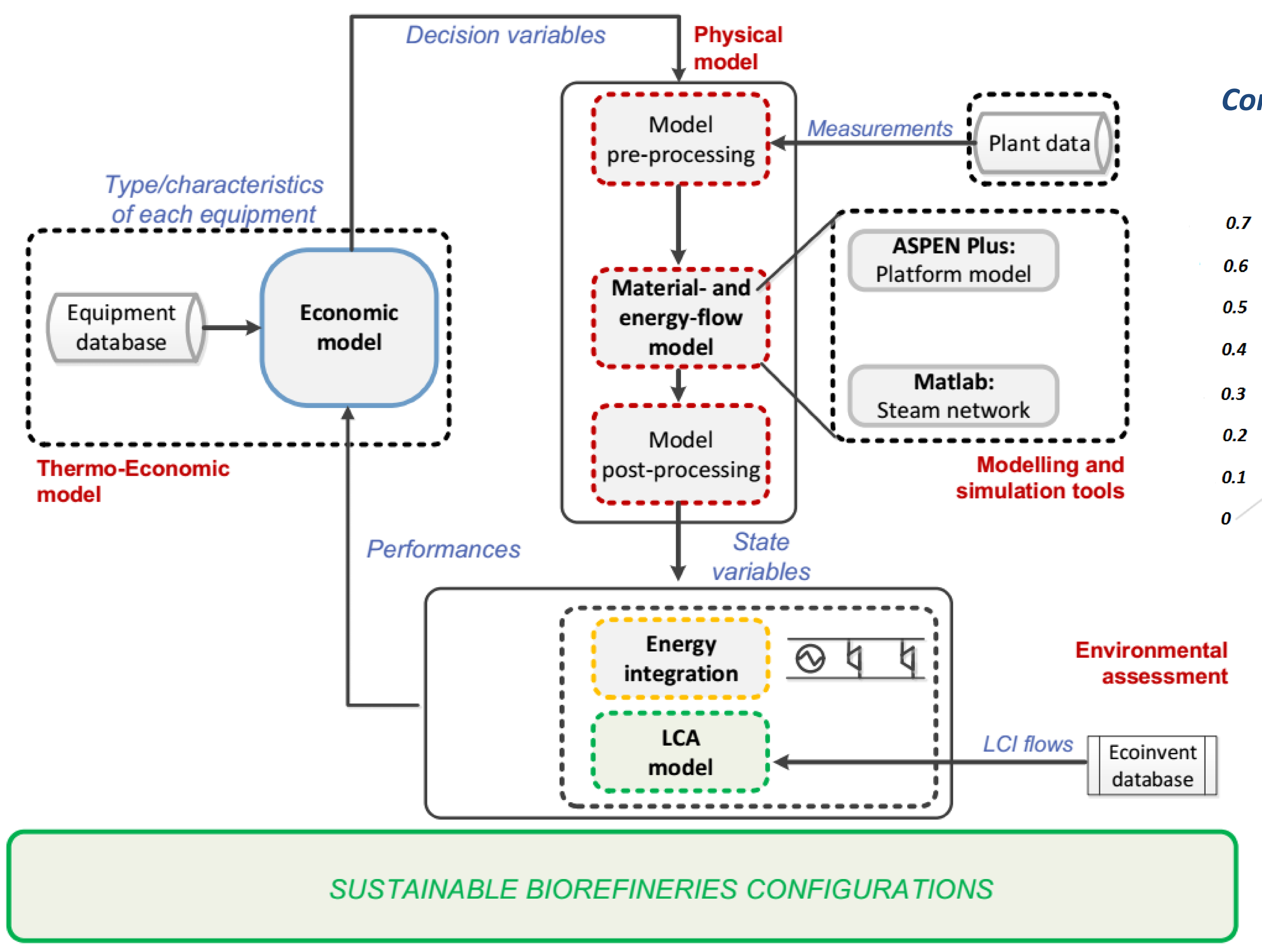
Stream	*m (kg/s)*	*T (°C)*	*P (bar)*	*b (kJ/kg)*
Sugarcane	138.9	25	1	5750
Bagasse for cogeneration	22.4	30	1	9979
Bagasse for hydrolysis	15.3	30	1	9979
Must	110	30	1	3520
Lignin cake	6.5	50	1	10.80
Wine	147	32	1	2102
Enzyme	0.6	29	1	23.73
Vinasse	135	75	1.4	440
Anhydrous ethanol	9.6	78	1	29.15

DESIGN OPTIMIZATION METHODOLOGY

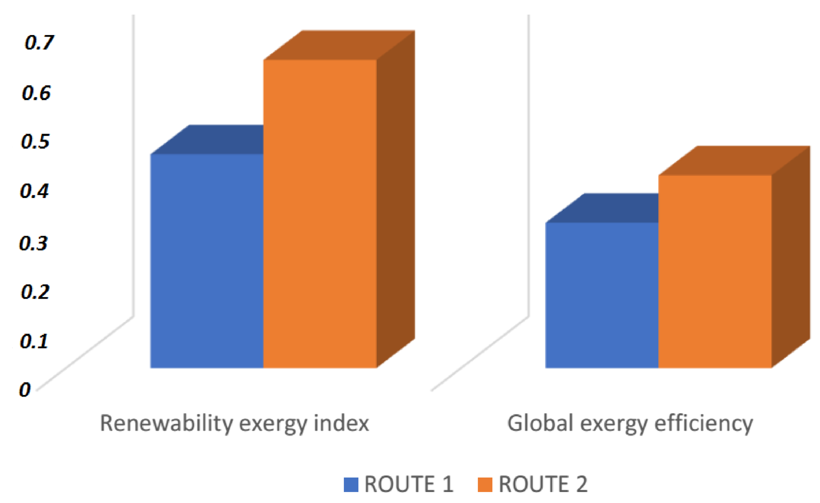
Global analysis of the evaluated technological routes

RESULTS





Comparison between renewability exergy index and global exergy efficiency



Average unitary exergy cost	
1G AUTONOMOUS DISTILLERY	3.42
1G2G AUTONOMOUS	2.57

SCIENTIFIC PAPERS

SILVA ORTIZ P., OLIVEIRA JR. S., *Exergy analysis of pretreatment processes of bioethanol production based on sugarcane bagasse.* **Energy, 2014, Vol. 76, p.130-138** http://dx.doi.org/10.1016/j.energy.2014.04.090

SILVA ORTIZ P., OLIVEIRA JR. S., *Compared exergy analysis of sugarcane bagasse sequential hydrolysis and fermentation and simultaneous saccharification and fermentation.* **Int. J. Exergy, Vol. 20, No. 1, 2016** https://doi.org/10.1504/IJEX.2016.075880

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