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Strategic selection of sugarcane biomass pre-tratments for centralized biorefineries in Brazil: a fuzzy multi-criteria decision approach

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STRATEGIC SELECTION OF SUGARCANE BIOMASS PRE-TREATMENTS FOR CENTRALIZED BIOREFINERIES IN BRAZIL: A FUZZY MULTI-CRITERIA DECISION APPROACH

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1. INTRODUCTION

Sugarcane biomass opportunity: Sugarcane bagasse and straw are abundant lignocellulosic residues with high potential to support Brazil's advanced biorefineries, especially as energy optimization in 1st ethanol plants can reduce steam demand from about **506 to 315 kg steam/t cane**, increasing the availability of surplus biomass for advanced thermochemical routes.

Centralized BtL/PBtL biorefinery concept: The surplus biomass can be upgraded through pre-treatment routes and transported to a centralized hub for gasification, syngas production, and biomethanol synthesis.

Need for decision support: Because each pre-treatment route has different technical, energetic, environmental, and logistic impacts, **Fuzzy-AHP/MCDA** [1] was applied to rank the most suitable alternatives for the studied biorefinery concept.

2. GOALS

To apply **Fuzzy-AHP** as a decision-support method to rank sugarcane bagasse (SB) and straw (SS) **pre-treatment** routes for **centralized gasification based BtL/PBtL biorefineries** focused on biomethanol production

3. METHODOLOGY

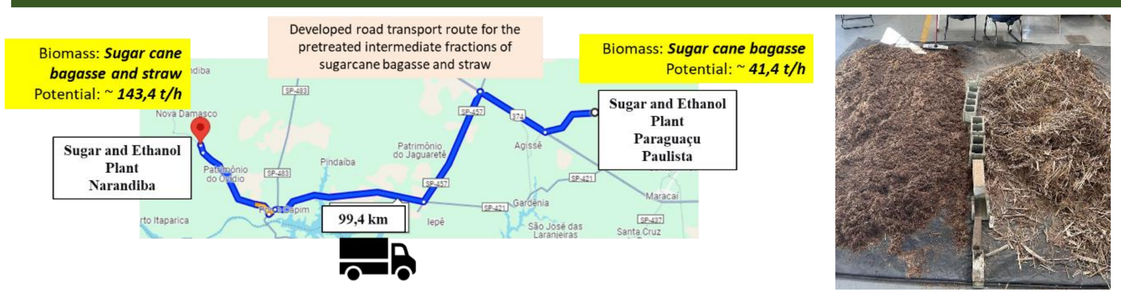


Figure 1 —Potential of biomass from both mills and the road-transport distance between them. Samples of SB and SS from Plants used in GALP 94 Project

	Critéria (i)
1	Product with high energy density (MJ/m³)
2	Reduction of elemental nitrogen
3	Reduction of elemental sulfur
4	Reduction of elemental chlorine
5	Reduction of alkaline ash content
6	Energy yield of the intermediate product
7	Electrical energy consumption in the process
8	Water consumption in the process
9	Reduction of moisture/water content
10	Handling safety of the intermediate product
11	Flowability/feedability under high pressure
12	Ease of implementation

	Alternatives (j)
1	Conventional fast pyrolysis producing bio-oil
2	Oxidative pyrolysis producing bio-slurry
3	In situ catalytic pyrolysis producing bio-oil
4	In situ catalytic pyrolysis producing bio-slurry
5	Natural pellets (in natura)
6	Pellets with residual plastics as binder
7	Pellets with fusel oil as binder
8	Clean biomass via pneumatic classification at high velocities
9	Clean biomass via pneumatic classification at low velocities
10	Biomass torrefaction under conventional atmosphere
11	Biomass torrefaction under oxidative atmosphere
12	Biomass torrefaction with superheated steam
13	Steam-exploded biomass with low severity factor
14	Steam-exploded biomass with high severity factor
15	Combined process 1: Pneumatic classification + torrefaction
16	Combined process 2: Pneumatic classification + steam explosion
17	Combined process 3: Torrefaction + pelletization

Figure 2 - Criteria (i) and pre-treatment alternatives evaluated (j) in MCDA-AHP fuzzy

Pairwise comparison
↓
Qualitative → Numerical [2]
trapezoidal fuzzy scale [l, m, n, u].
↓
geometric mean aggregation
↓
defuzzification by centroid method
↓
criteria weights

Final ranking

The criteria weights were combined with experimental and qualitative performance data to rank the 17 pre-treatment routes

4. RESULTS

Fuzzy-AHP showed that the most relevant criteria for selecting pre-treatment routes were:

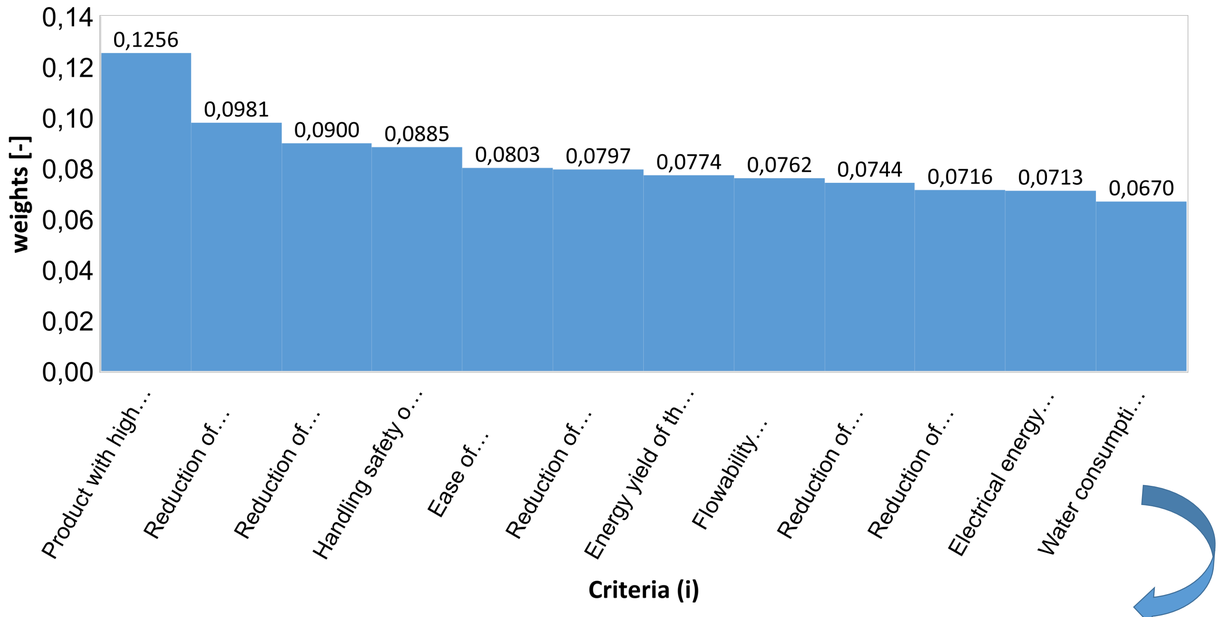
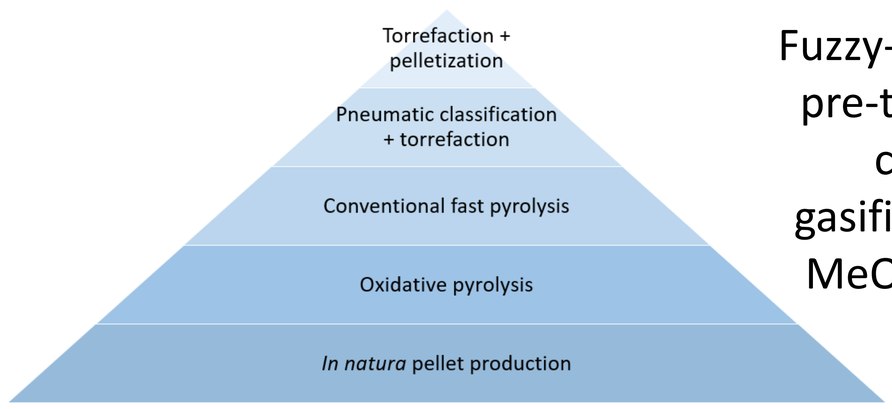


Figure 3 – Most important decision criteria

Product with high energetic density, contaminant reduction, and Ease of implementation were the main drivers for technology selection.

- Best-ranked pre-treatment routes



Fuzzy-AHP ranked 17 pre-treatments for centralized gasification for bio-MeOH production

Figure 4 – Best-ranked pre-treatment routes

Torrefaction is a strategic pathway to connect decentralized sugarcane mills with a centralized biomethanol hub

5. CONCLUSIONS

- Fuzzy-AHP method successfully combined **experimental data, expert judgment, and technical–logistic criteria** to rank biomass pre-treatment routes for centralized BtL/PBtL biorefinerie.
- Torrefaction-based routes were the most promising Routes showing the best balance between: energy density, contaminant reduction, handling safety, implementation feasibility.

6. BIBLIOGRAPHY

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