

Integrated production of chemicals and fuels in the pulp industry: techno-economic and environmental analysis of black liquor gasification-based processes

Meire Ellen Gorete Ribeiro Domingos^{a*}, Daniel Flórez-Orrego^b, Silvio de Oliveira Junior^c, François Maréchal^b, Moisés Teles dos Santos^{a*}

^a Polytechnic School, University of Sao Paulo, Department of Chemical Engineering, Sao Paulo, Brazil

^b École Polytechnique Fédérale de Lausanne, Valais, Sion, Switzerland

^c Polytechnic School, University of Sao Paulo, Department of Mechanical Engineering, Sao Paulo, Brazil

* meireallengorete@usp.br / moises.teles@usp.br

Introduction

Pulp and paper sector:

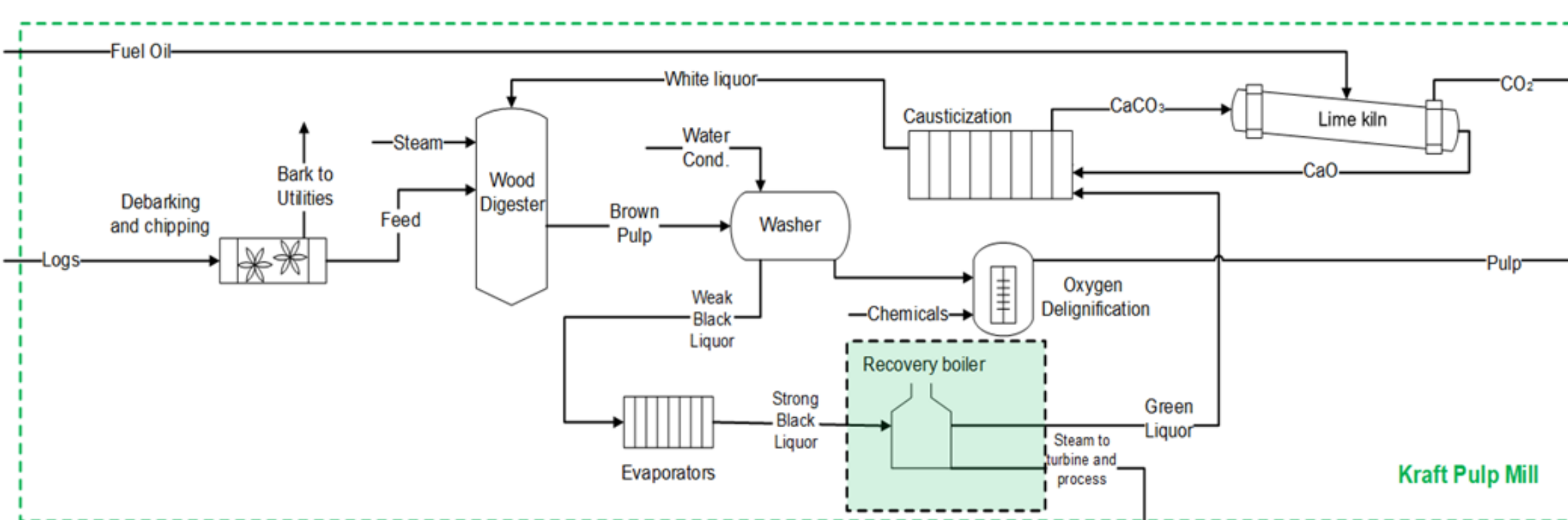
Brazil: the **2nd** largest producer of pulp in 2020 [1].

Energy-intensive: **5.6% of the total energy industrial consumption** [2].

Responsible for **2.3% of the total CO₂ emitted** [3].

Industrial challenges:

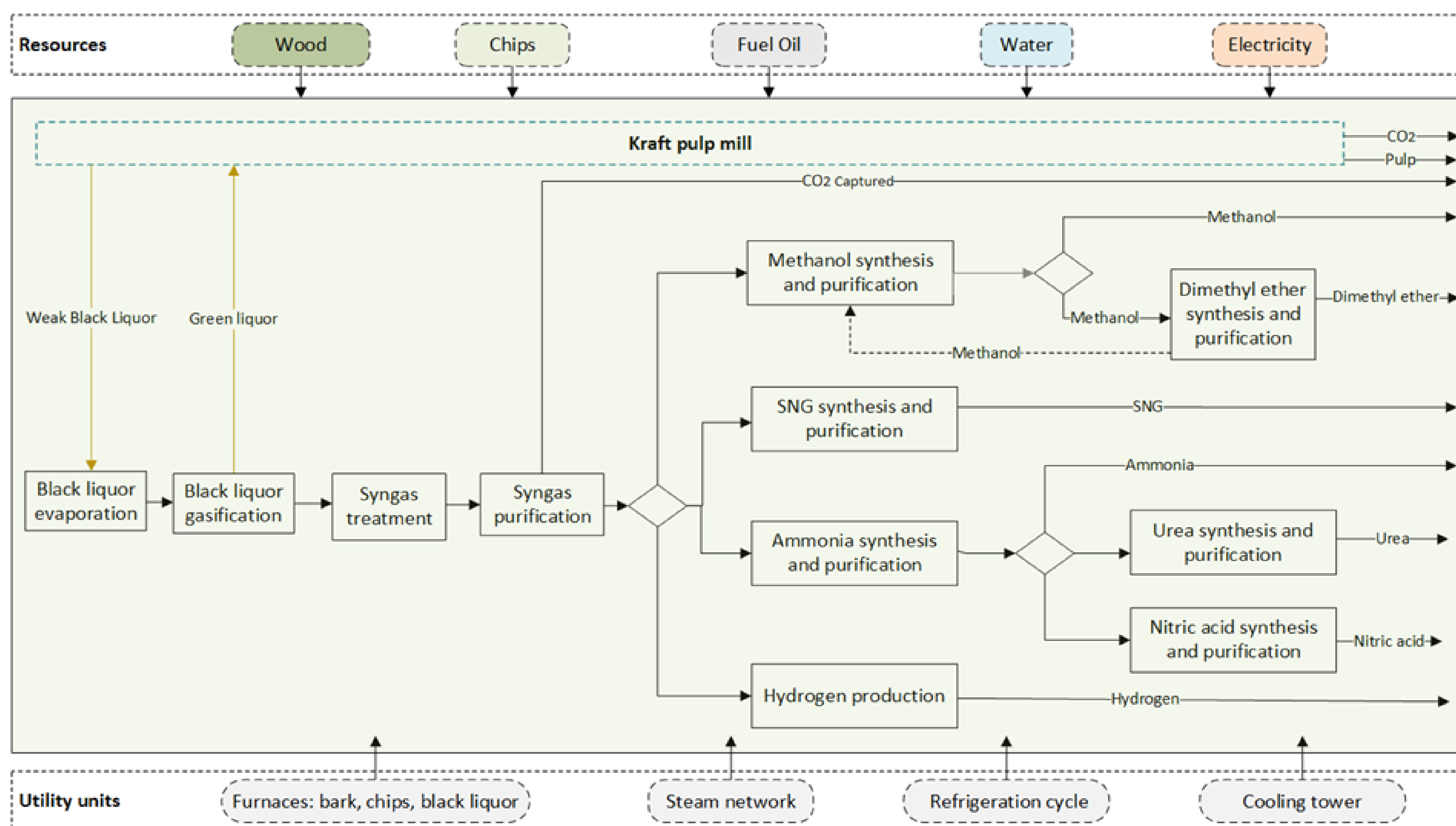
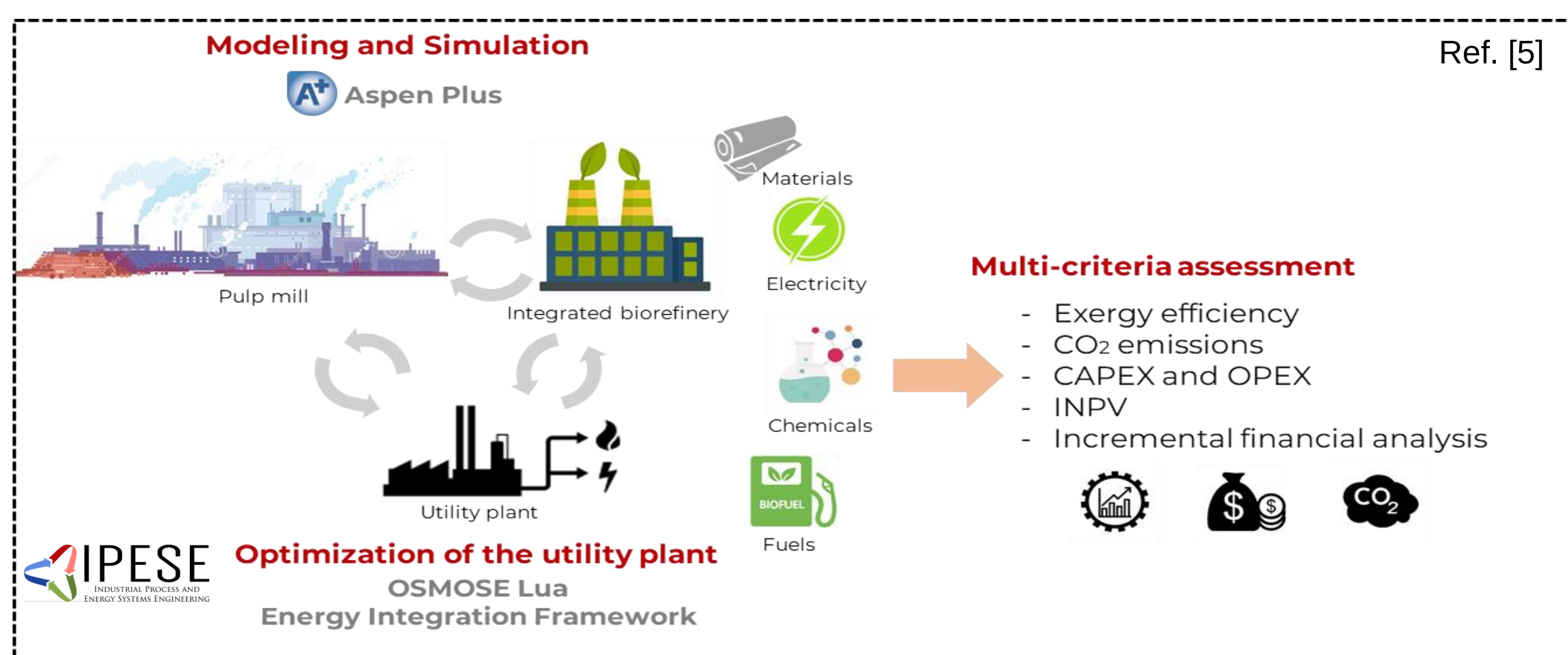
- Black Liquor (BL) evaporation: **consumes 50% of the steam** produced in the plant.
- Power generation efficiency (recovery boiler) [4]: 9-14%.
- Evaporation + combustion of the BL → the **largest CO₂ emissions**.



In this work is performed:

- the detailed analysis of the simultaneous production of pulp and fuels/chemicals;
- the implementation of an optimization framework that minimizes energy requirements of the alternative routes proposed;
- the consideration of the inefficiencies associated to the different upstream supply chains;
- an incremental financial analysis considering different carbon taxes and market conditions.

Methodology



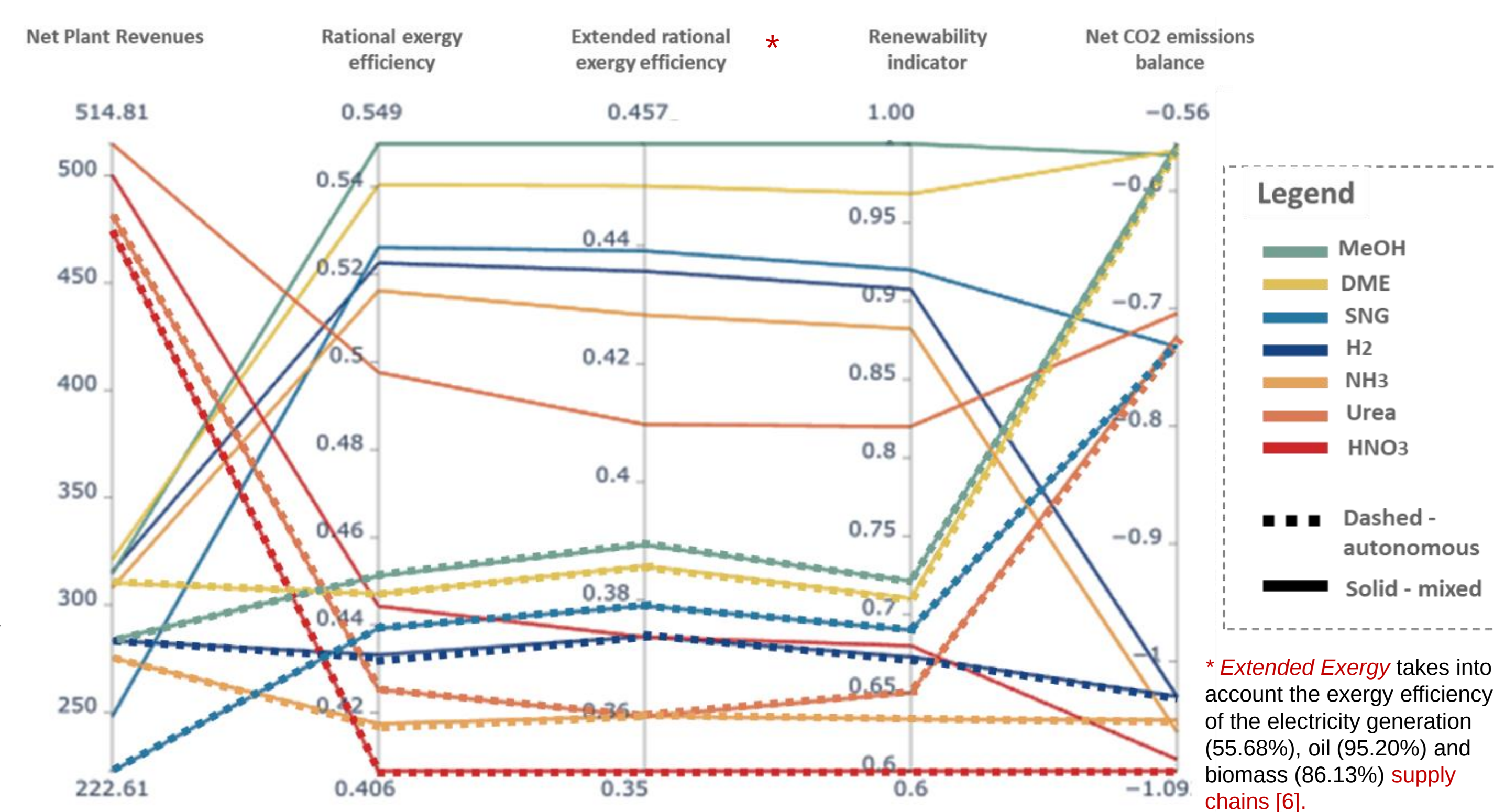
Scenarios:

- Conventional** → recovery boiler application, no fuels/chemicals production
- Mixed** → based on both chips fuel and **electricity import**, fuels/chemicals production
- Autonomous** → **only chips** import and **cogeneration** system enabled, fuels/chemicals production

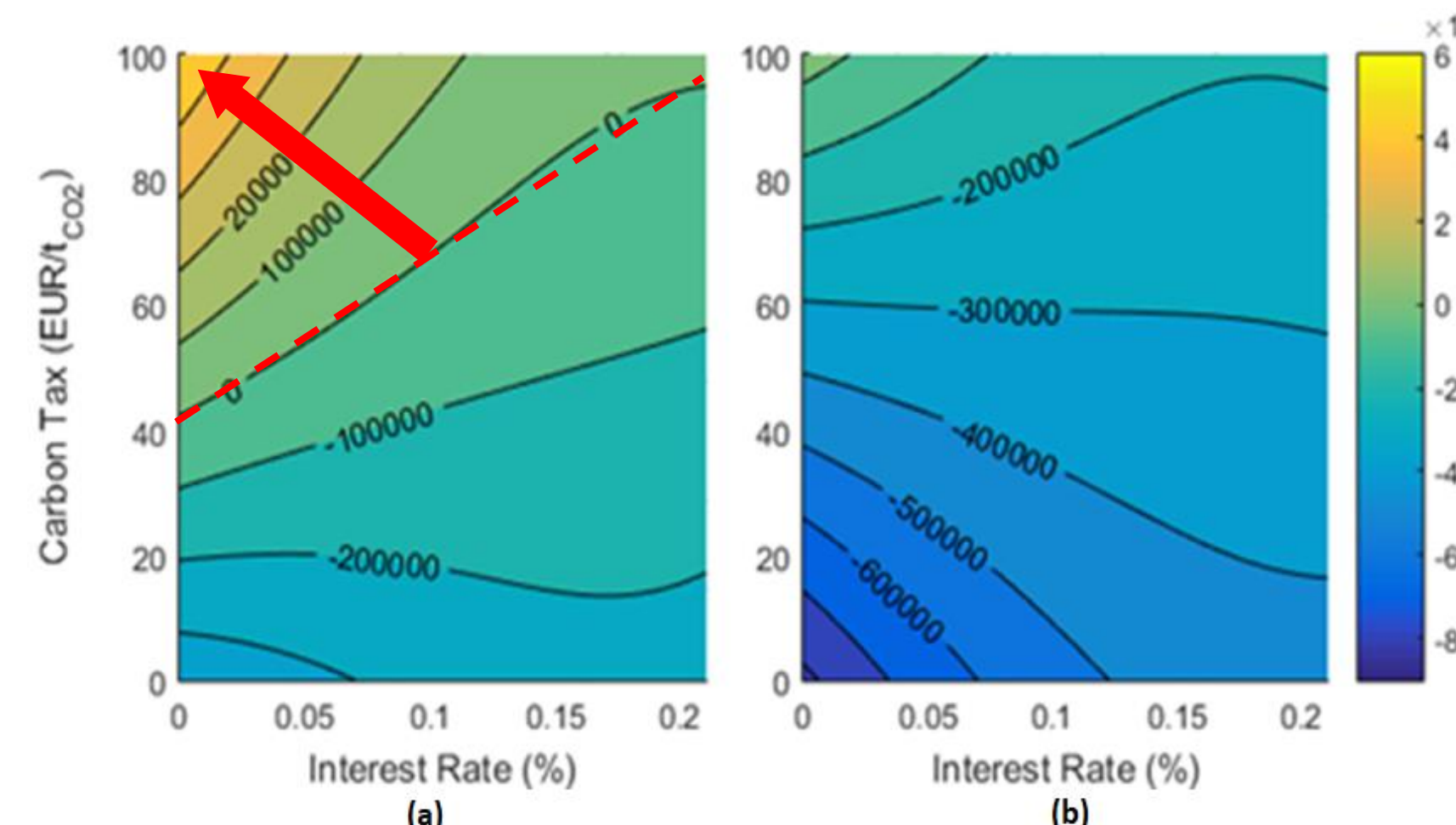
Results

Main findings:

- the relation between the different indicators is not linear;
- as the upstream supply chain inputs are included in the analysis, the typical overall efficiencies are reduced;
- all the **mixed cases** presented higher efficiencies and renewability performance, except for the nitric acid (excess heating).



Contour plots of INPV (Euro) variation for the integrated kraft pulp process and ammonia production under mixed (a) or autonomous (b) operating modes:



- Mixed** may economically outperform the autonomous setup, depending on the interest rate adopted, for moderate carbon taxations (40-100 EUR/t_{CO2}).
- Autonomous** is not economically feasible even at higher carbon tax.

Results of the ranking obtained using the TOPSIS method*:

Fuels and chemicals	Results	Rank
H2 Mixed	0.75	1
NH3 Mixed	0.73	2
SNG Mixed	0.68	3
H2 Autonomous	0.61	4
NH3 Autonomous	0.59	5
SNG Autonomous	0.56	6
MeOH Mixed	0.56	7
DME Mixed	0.54	8
MeOH Autonomous	0.46	9
DME Autonomous	0.42	10
HNO3 Mixed	0.41	11
HNO3 Autonomous	0.40	12
Urea Mixed	0.29	13
Urea Autonomous	0.18	14

* Weight 0.2 for all KPI's reported in the parallel coordinates graph

For all the chemicals, the mixed setup outperformed the autonomous mode, reinforcing the **benefits of the diversification of the energy inputs** and also the favorable **Brazilian context** to the implementation of biorefineries.

Conclusion

- BL gasification for chemicals/fuels production proves to be useful in **reducing the exergy consumed and net CO₂ emissions**, whereas maintaining attractive the revenues of the integrated plant.
- The best alternatives of utility systems** maximize the recovery of the available waste heat exergy.
- The exergy efficiencies of the conventional and integrated cases average 40% and 43%, respectively, whereas the net emission balance varies from 0.26 to -1.09t_{CO2}/t_{Pulp}, respectively. The negative values point towards the environmental benefits brought about by **the production of chemicals through the use of alternative energy sources such as biomass**.
- The **electricity import**, whenever available, may **help reducing the extent of the irreversibility and chips consumption rates** in the integrated systems, as well as reducing the overall CO₂ emissions.
- The method can help the **decision making** considering **market fluctuations** in the context of more stringent regulatory commitments aiming to increase the sustainability of the process.

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