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

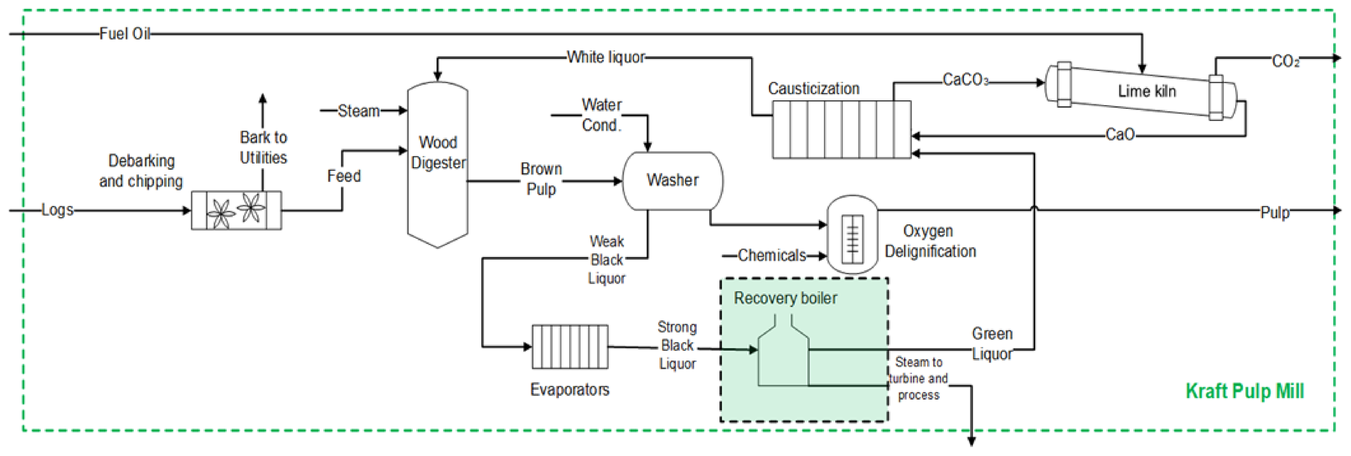
Introduction

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 CO_2 emitted** [3].



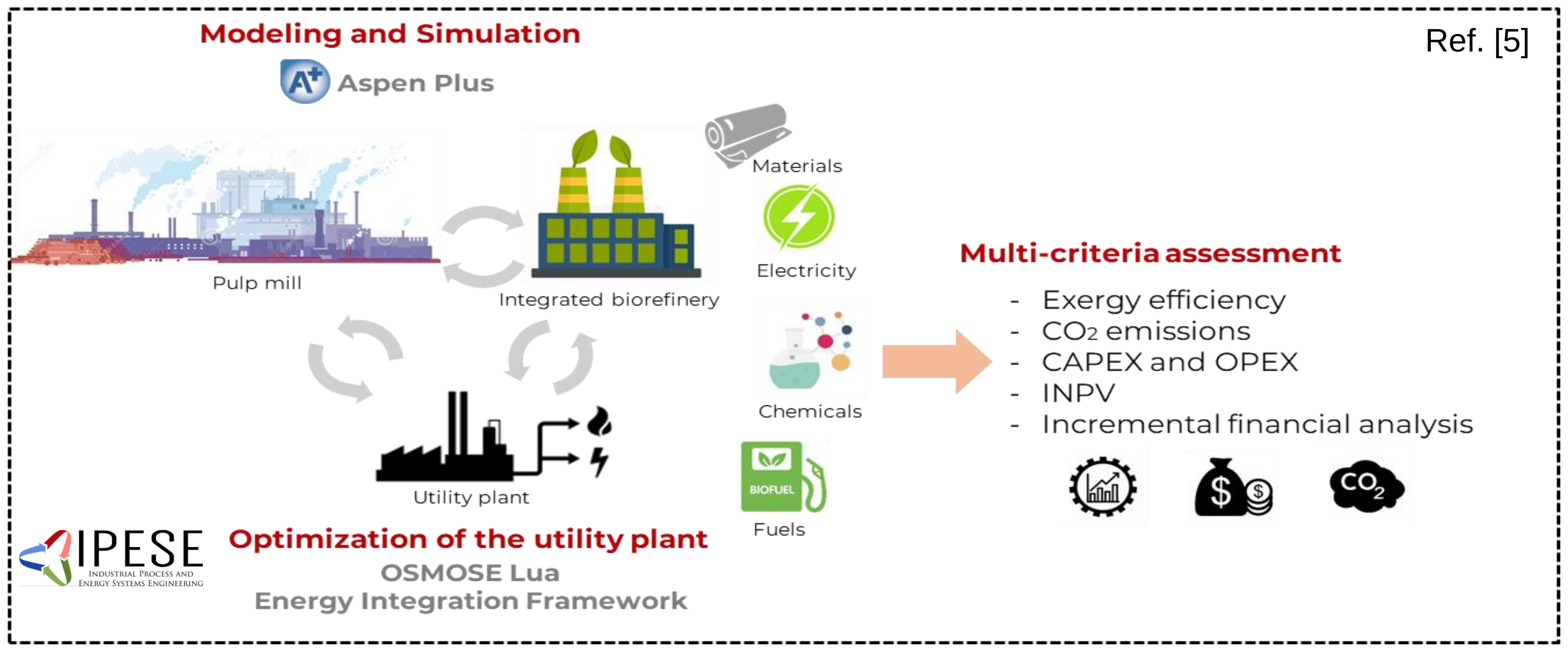
Industrial challenges:

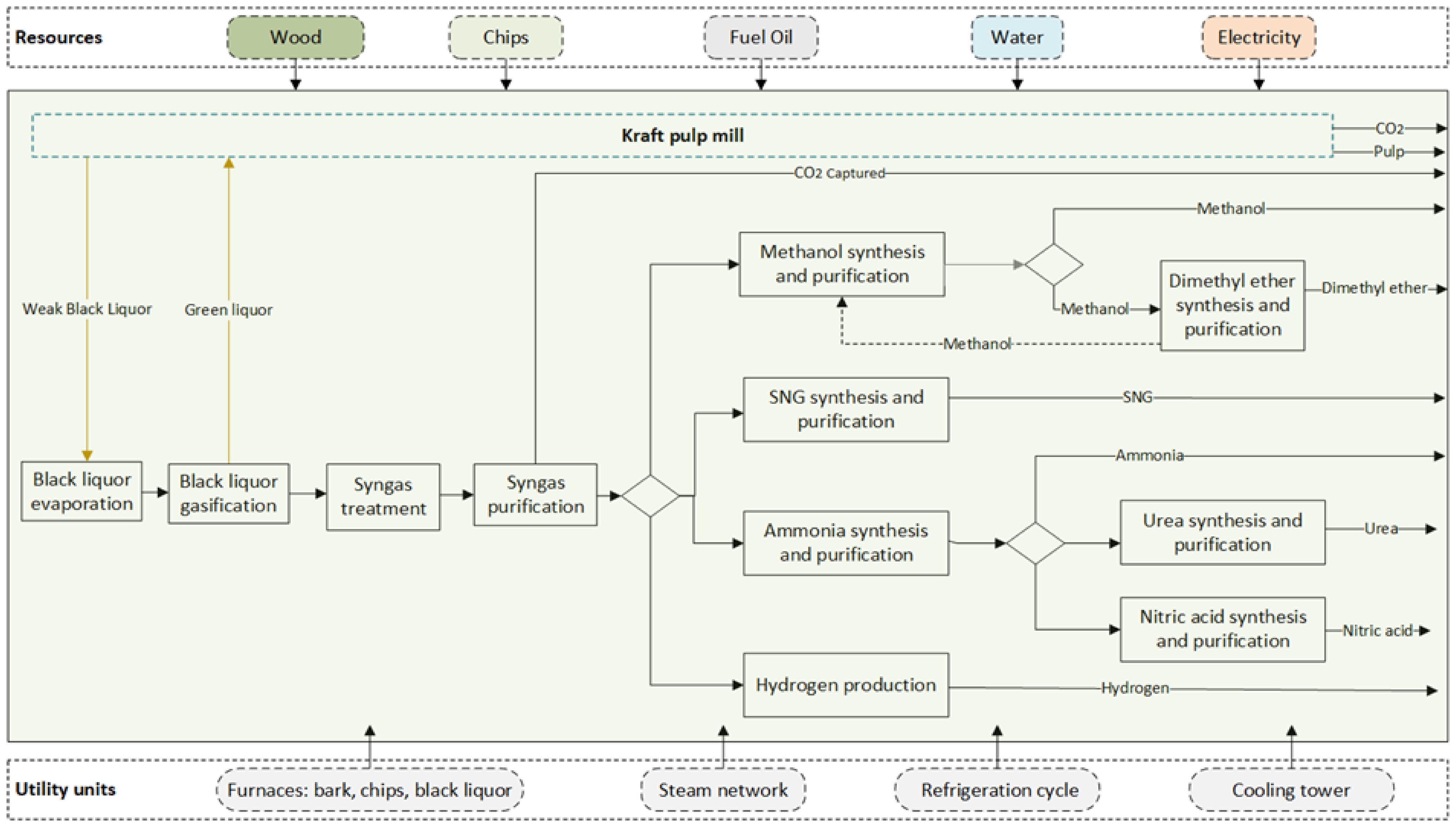
- Black Liquor (BL) evaporation: **consumes 50% of the steam** produced in the plant.
- Power generation efficiency (recovery boiler) [4]: 9-14%.
- Evaporation + combustion of the BL → the **largest CO_2 emissions.**

In this work is performed:

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

Methodology





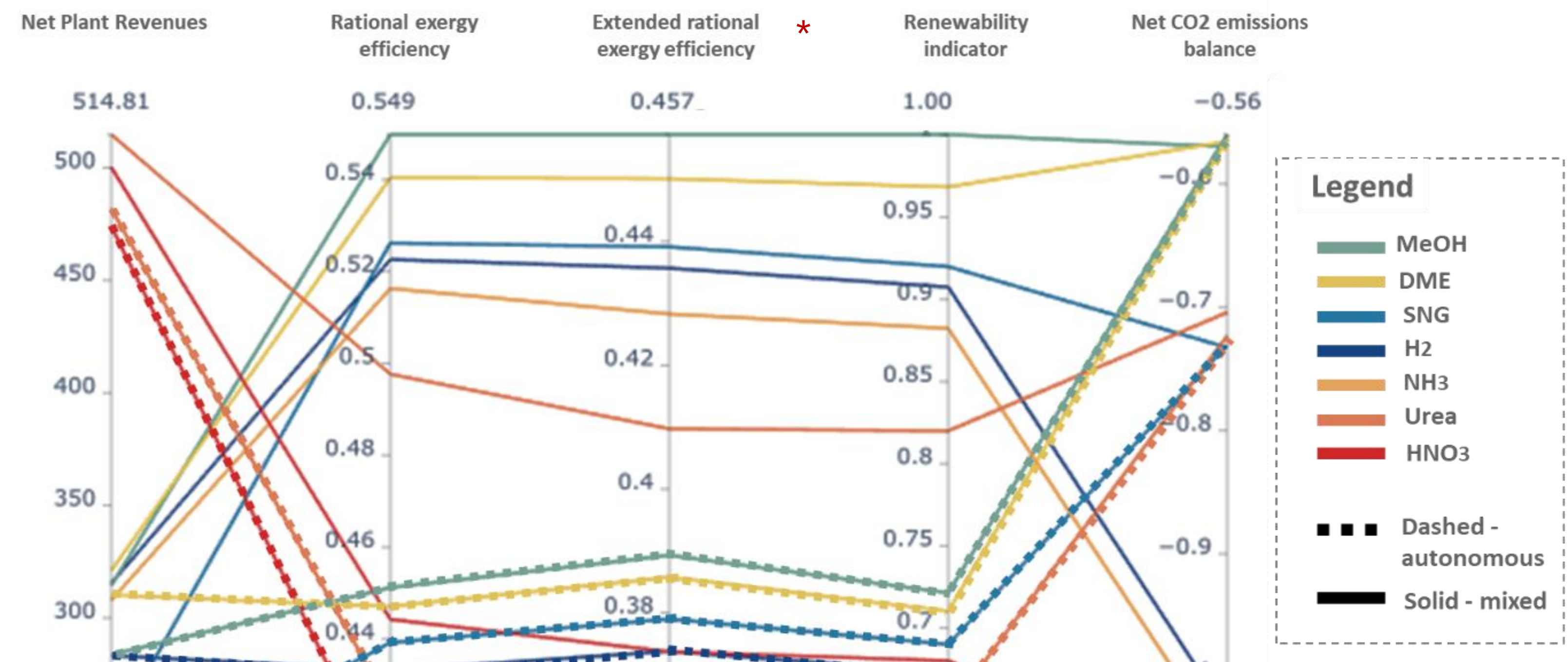
Scenarios:

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

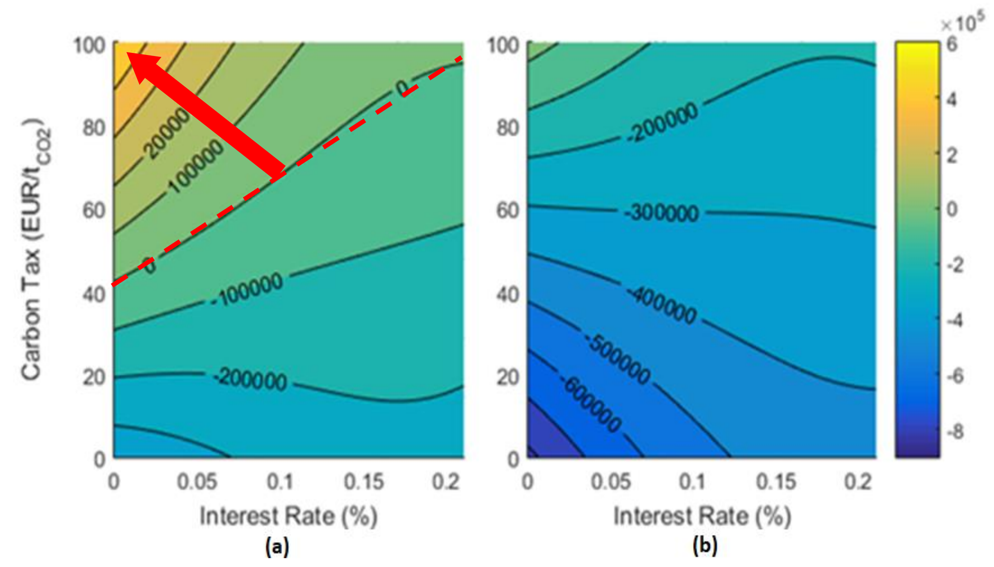
Main findings:

- 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).



* Extended Exergy takes into account the exergy efficiency of the electricity generation (55.68%), oil (95.20%) and biomass (86.13%) supply chains [6].

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

* Wheight 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 CO_2 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 CO_2 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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Acknowledgements

The first author thanks the Brazilian National Research Council for Scientific and Technological Development, CNPq (grant 142148/2019–9), and the Swiss Government Excellence Scholarship (ref. 2021.0235). Second author would like to thank the Colombian Administrative Department of Science, Technology and Innovation – Minciencias (COLCIENCIAS Grant 1.128.416.066–646/2014). The third author thanks CNPq (grant 306484/2020–0).