Ex-ante Life Cycle Assessment of the energy production in a paper and pulp mill

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Climate change is one of the biggest problems we face as humans. The main contributor to the accelerated increase in greenhouse gases (GHG) emissions is the burning of fossil fuels. Different economic sectors have started prioritizing measurements to reduce their dependency on fossil-based carbon for materials and energy purposes. The paper and pulp (P&P) industry use renewable carbon (trees) for materials production (P&P). However, the processing of trees to pulp requires much energy (Francis et al., 2004). Around 30% of the energy demand in the P&P industry is supplied from fossil resources (coal and/or natural gas) (Vass et al., 2021). Sustainability Development Goals (SDGs) are used as guidelines in the P&P industry to set reduction targets of GHG emissions and reduce the dependency on fossil fuels. One of the promising developments is the use of renewable energy from waste streams from their operations, especially from forestry operations and the chipping. Several tons of waste biomass (mostly branches and tops from forestry operations) are left on the field after trees are cut and collected to be transported to the mill. Previous studies reported a heating value ranging from 17 to 20 MJ/kg (Silveira et al., 2020; Zhou et al., 2011). Combustion boilers are normally used to directly burn biomass into energy. However, research has focused on other thermochemical technologies (e.g., gasification, pyrolysis) that provide better benefits than the direct combustion. Some advantages of gasification are the high value retention (conversion of biomass to synthesis gas) and high energy efficiency (27% electricity efficiency and 61% heating efficiency) (Dong et al., 2018).

This work aims to perform an ex-ante environmental assessment of the production of bioenergy using two study cases: a) a reference case with the current operative conditions of the mill, and b) a future case with the addition of a gasifier unit for energy production in the mill. Life cycle assessment (LCA) is used as a methodology to quantify the environmental impact of the production of energy in the mill (Corcelli et al., 2018). Uncertainty analysis (using Monte Carlos simulation) is included to evaluate the effect of the technology maturity in the overall environmental performance of both cases. Scenario analysis is used to assess the different alternatives to supply renewable fuel for the future case of energy production in the P&P mill. Finally, a hotspot analysis is carried out to determine the main contributors to the overall environmental impact of bioenergy production.

1. Methods

A P&P mill is a well-integrated process where inputs and outputs are valorized and optimized. Wood logs are transported to the mill for processing into wood chips. Then, chips are digested through the Kraft process using white liquor (sodium hydroxide and sodium sulfide) to produce unbleached pulp as the main product and black liquor as co-product. White liquor is recovered from the black liquor through a series of steps involving the combustion of black liquor and causticizing. Production of electricity and steam is done by the valorization of by-product streams (e.g., black liquor, sludge, screen rejects), and the use of external fuels (e.g., coal, natural gas, biomass). Different technologies (e.g., power boiler, gas turbine, gasifier) are used to produce energy in the mill. This paper aims to perform an ex-ante life cycle assessment (LCA) of the energy production in the P&P mill using two main cases: a) reference case – current operating conditions of the mill, and b) a new case where a gasifier unit is added to the mill to generate fuel to replace fossil gas in the lime kiln (part of the white liquor recovery. Two scenarios are considered for the futuristic case:

- **Scenario 1** – Treetops from forestry operations and external companies (procured biomass) are used as fuel in the power boiler.
- **Scenario 2** –Sugarcane bagasse is used as fuel for the power boiler. Sugarcane bagasse could be available in the surroundings of the mill, and therefore it could be considered a potential source of energy.

In this study, the production of 1 MJ of electricity from the energy recovery area was selected as the functional unit. The LCA includes different stages from the extraction of raw materials (forestry operations) until factory-gate. The use phase and end-of-life stages were not included in this study. Foreground data (mostly mass and energy balances) of the reference and future cases were collected by direct communication with the P&P mill. Assumptions of the future case and scenarios were included where needed for completeness of the LCA model. Background data (e.g., electricity production) were collected from the Ecoinvent database v7.0 (Ecoinvent, 2020). ReCiPe hierarchist v1.3 was selected as the impact assessment method. The propagation of error in the results from the ex-ante LCA was assessed through an uncertainty analysis using Monte Carlo simulation. Additionally, the processes (e.g., units) with the highest contribution to the overall environmental impact were determined in the hotspot analysis.

2. Results

The reference case presented a higher global warming potential (GWP) than any of the scenarios for the future case, as summarized in **Figure 2a**. However, the results of the scenarios are attained to considerable uncertainty, which might represent a higher GWP than the reference case. The main processes contributing to the GWP were determined and represented in **Figure 2b**. The emissions to air from the burning of black liquor and the use of natural gas for the limekiln are the main hotspots of the reference case, accounting for 30% and 20% of the total GWP, respectively. Similarly, air emissions from the production of energy from burning biomass, and the use of natural gas as energy sources in the gas turbine are the main hotspots of the scenarios for the future case, accounting for 40% and 20% of the total GWP, respectively. For the future case, the use of synthesis gas instead of natural gas in the limekiln could mitigate the GWP compared to the reference case.

Other impacts categories - agricultural land occupation potential (ALOP), water depletion potential (WDP), terrestrial acidification potential (TAP), and particulate matter formation potential (PMFP) were evaluated; however, results are not presented in this abstract due to space limitations.

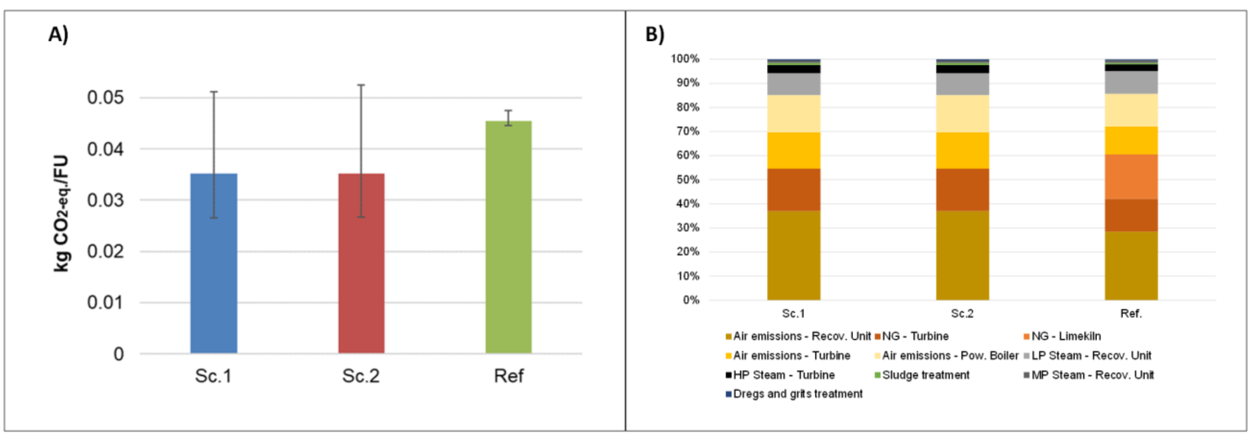

Figure 2. (a) Overall environmental impact (GWP) and (b) hotspot analysis of evaluated scenarios.

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