Biorefinery Alternatives in a Pulp and Paper Mill: Evaluation through Multi-Criteria Analysis

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Biorefinery has been defined by the International Energy Agency as the sustainable processing of biomass into a spectrum of marketable products and energy (IEA, 2019). A biorefinery can be a standalone facility or can be implemented within an existing facility such as a pulp and paper (P&P) mill to share feedstock, energy, and material resources. The P&P industry convert predominantly woody plant material into a wide variety of pulps, papers, and paperboards.

In this work, the main residue of a sulphite pulp mill, the so-called spent sulphite liquor (SSL) served as a feedstock for three biorefinery models to be developed. SSL mainly contains sugars and lignosulphonates. During the acidic sulphite process hemicellulose is degraded liberating xylose, mannose, arabinose, galactose, and acetic acid. SSL also contains glucose coming from the hydrolysis of cellulose (Llano et al, 2015). Using these C5 and C6 sugars as a platform, the production of three biofuels and bio-products were simulated among other products tested previously (Rueda et al., 2015) taking into account the market, the price, and the availability of the appropriate sugar substrate in the SSL: xylitol, furfural, and ethanol. Three models were simulated by Aspen Plus to decide the best biorefinery alternative (Fig. 1).

Detoxification, fermentation, and purification stages are included in the models presented in Fig. 1. Based on a previous study by Llano et al. (2017), is necessary to remove all the inhibitors presented in the SSL before fermentation. Among all the fractionation methods tested, anionic resins and overliming were the selected and modelled techniques in the three SSL-based biorefineries. Final productions were 15.84, 19.92 and 14.64 $t \cdot day^{-1}$ of xylitol, furfural and ethanol using 1970 $t \cdot day^{-1}$ of SSL (Rueda et al, 2016).

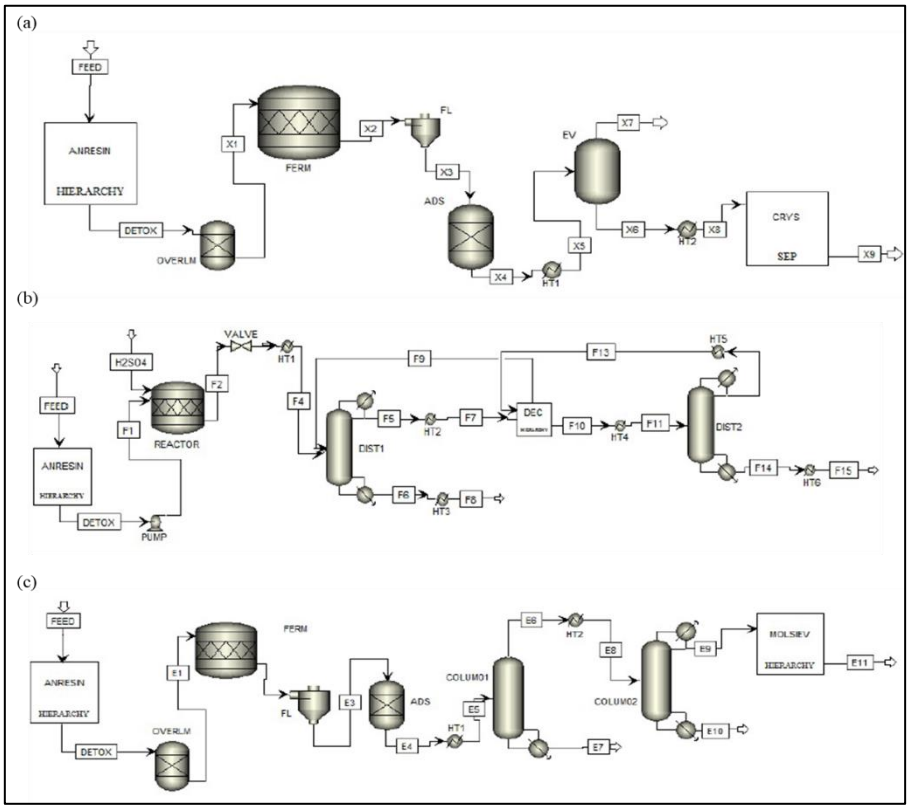

Figure 1. Flowsheet schemes of the proposed SSL-based biorefineries processes: (a) xylitol; (b) furfural; (c) ethanol.

As there is a complex mixture of technical and economic variables, to get a final decision about which one of the three aforementioned biorefineries is the most suitable from a techno-economic perspective, a multi-criteria analysis (MCA) decision-making tool has been applied in this research. The best alternative was selected considering the following criteria: market, price, production, fixed capital invested (FCI), manufacturing costs (COM), and payback period (PBP).

The decision matrix and the proposed scenarios are shown in Table 1. These data were introduced in the Definite 3.1 software. The first scenario (SC1) was conducted using the Analytic Hierarchy Process (AHP). In this case, all criteria were considered with the same importance and evaluated in pairs. Three more scenarios (SC2, SC3, and SC4) were carried out and the weight distribution of each one of them is shown in Table 1. The MCA results and ranking scores of the three biorefinery models (alternatives) for each scenario are plotted in Fig. 2.

Table 1. Criteria and alternatives assessed in this work and weighting distribution of the proposed scenarios.

CRITERIA (C)	Alternatives (A) Biorefinery models			Scenarios (SC) Weights Distribution (%)			
	A1. Xylitol	A2. Furfural	A3. Ethanol	SC1-AHP	SC2	SC3	SC4
C1. Market (ton/y)	242,000	250,000	46,000,000	16.7	0.0	33.3	0.0
C2. Price (€/ton)	5830	500	740	16.7	0.0	33.3	0.0
C3. Production (t/day)	15.84	19.92	14.64	16.7	33.3	33.3	50.0
C4. FCI (M€)	5.13	4.25	6.01	16.7	33.3	0.0	0.0
C5. COM (M€/y)	4.83	3.59	4.20	16.7	33.3	0.0	0.0
C6. PBP (years)	0.32	10	10	16.7	0.0	0.0	50.0

Xylitol is the best alternative in all studied scenarios except in SC2 where costs (FCI and COM) and production are the only weighted criteria. In this case, the highest score was the furfural biorefinery (0.52) followed by xylitol (0.32), and ethanol (0.29). Based on the MCA methodology, it can be concluded that in terms of production, benefits, and fixed & variable costs, the SSL-based biorefinery for xylitol production is the most suitable alternative.

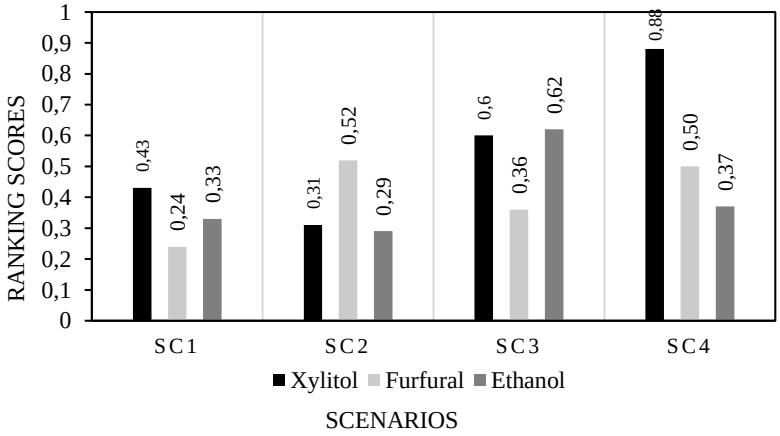

Figure 2. Ranking scores of the xylitol, furfural and ethanol biorefineries.

Sensitivity analysis was conducted to see how the ranking position of the biorefinery alternatives changes as the weight of one of the six criteria increases (Fig. 3). Xylitol is the best alternative in the whole weight range of C2 and C6, and above the weight of 60% for C3, C4, and C5; when **the weight of market (C1) is above 30 %, ethanol becomes the best alternative (Fig. 3a).**

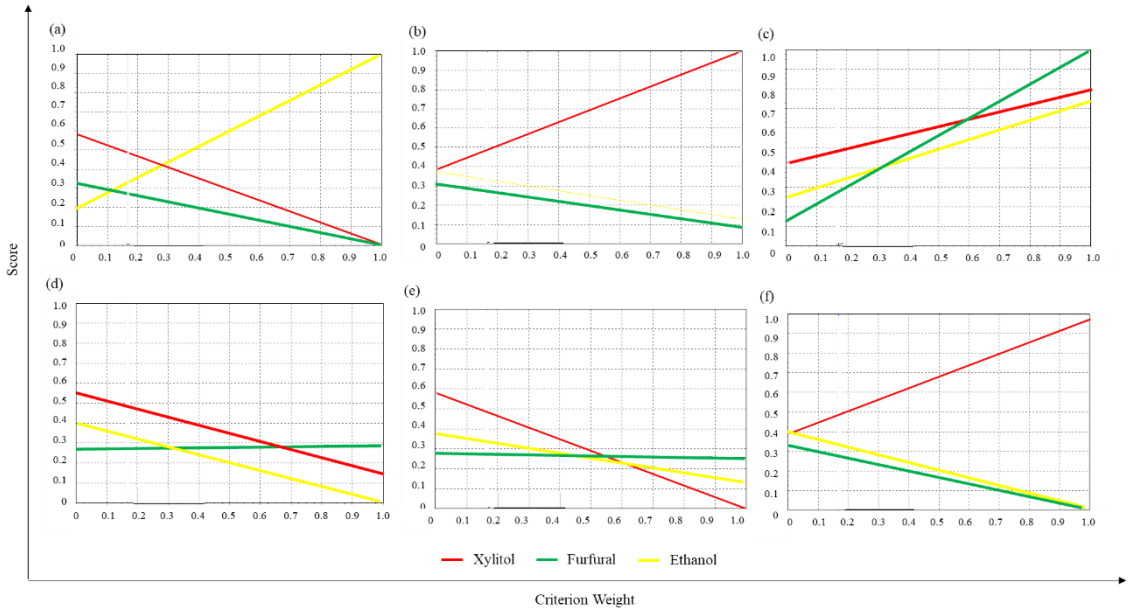

Figure 3. Sensitivity analysis of each of the criteria: (a) C1, (b) C2; (c) C3; (d) C4; (e) C5; (f) C6.

Acknowledgments

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