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The insertion of biogas in the sugarcane mill product portfolio: A study using the robust optimization approach

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ABSTRACT

Biogas generation from vinasse, a problematic residue from the ethanol process, has been discussed as an alternative to increase sustainability and profitability in the Brazilian sugarcane industry. Recent studies have widely assessed the technical feasibility of biogas projects. However, the economic impact of this new product on the overall results of sugarcane mills still needs to be addressed, as this is still an incipient technology in the sector. As price risks represent a significant issue for production decisions in the sugarcane industry, and they may be addressed through portfolio diversification, this paper aims to examine the implications of the insertion of biogas into their product portfolios. A risk measure broadly used in literature, CVaR, was applied in the optimization model proposed. Additionally, a robust counterpart for the model was developed to deal with price uncertainties and assess their potential impact on the portfolio decisions. The models were validated through both a *ceteris paribus* and a factorial analysis, and the results obtained allowed the understanding of the role that biogas production may play in the sugarcane industry. In both models, standard and robust, the use of biogas for the substitution of diesel stands out as the only economic application. The results also indicate that, for most of the price scenarios performed, electricity generation from biogas is not economically feasible. Furthermore, it was highlighted that the insertion of biogas into the portfolio yields a gain in the overall efficient frontier of sugarcane mills. Thus, in conclusion, this study presents strong evidence of the economic feasibility of biogas generation in the Brazilian sugarcane industry and the model developed to perform this analysis is shown to be a powerful tool to further assess the impact of price policies on their production decisions.

1. Introduction

The sugarcane sector is one of the main contributors to the Brazilian economy, representing a sectorial GDP of over US$113 billion in 2015 [1]. This important role in the national scenario is reflected in the country's position at the top of the world's sugarcane production ranking. In 2015, Brazil produced over 739 M tons of sugarcane, which established it as the largest producer in the world, with a volume greater than the sum of the six remaining nations [2]. Due to the sector's economic impotence, the Brazilian sugarcane industry has been the subject of intense study in the literature. Several authors [3–5] have proposed optimization models for sugarcane mills operation, whereas two main research topics stand out as particularly important for prevailing among the main challenges in the sector: waste management [6] and price volatility [7].

The processing of sugarcane for ethanol and sugar production generates a large amount of residues. Traditionally, the industry sought to reintegrate its waste into the production mix, thus avoiding waste disposal costs while new sources of monetization emerge. Accordingly, potential applications for the residues have been widely discussed in recent years, as they may contribute to greater sustainability in the sector, transcending its traditional use as fuel wood. The inclusion of activities defined as modern applications of biomass [8] enhances more economically efficient and sustainable purposes, such as electricity and fuel for transportation.

Along these lines, Hagman et al. (2018) [9] emphasize the potential of biogas projects to contribute to better sustainability performance in biorefineries. Particularly in the sugarcane sector, recent studies have examined the use of vinasse, a problematic residue from the ethanol process, for biogas production as an alternative to improve energy recovery from waste. Moraes et al. (2014) [10] evidences its technical feasibility, pointing to electricity generation and diesel replacement by biogas as the most promising economic uses. Pazuch et al. (2017) [11] assess the economic feasibility of a project to generate biogas from

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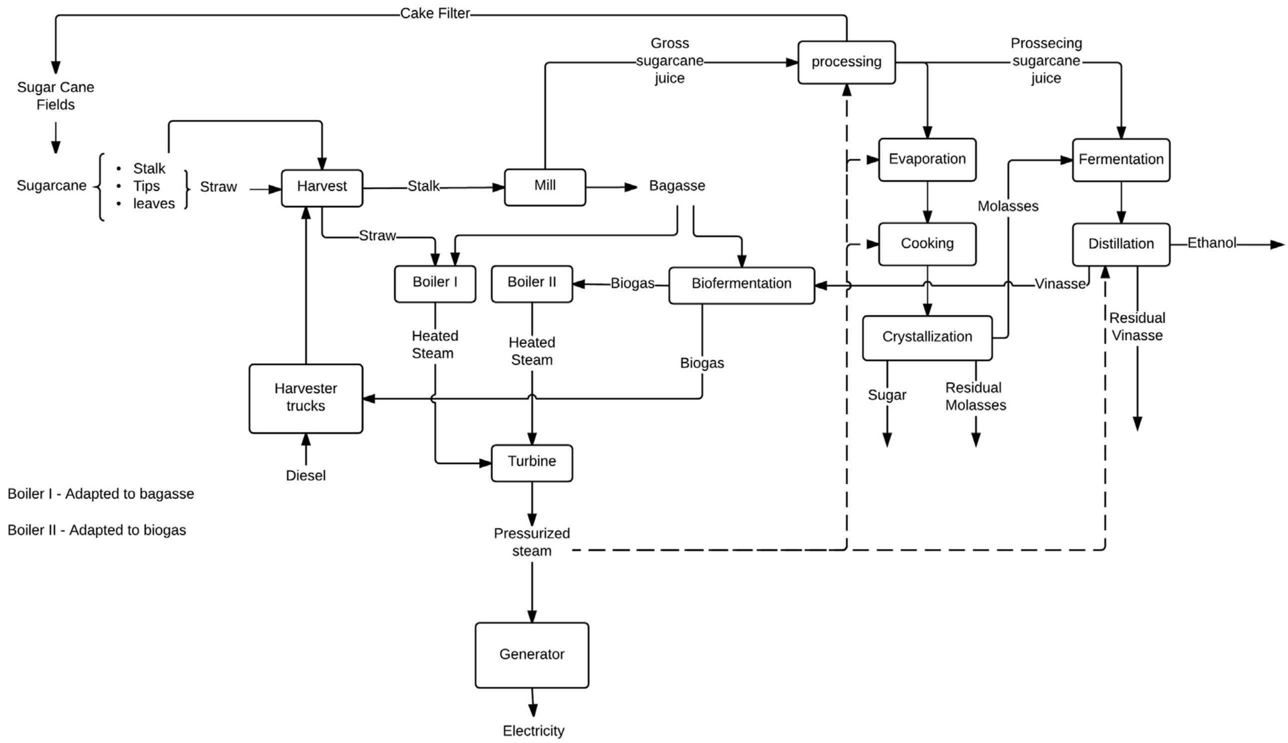

Fig. 1. Sugarcane industry production process.

vinasse at a sugarcane mill, enhancing its viability as a replacement for sugarcane bagasse, another large-scale residue in this industry, for power generation. However, both authors implement an economic analysis taking into account only the financial return of biogas destinations, through IRR and NPV techniques.

Bagasse is an example of a sugarcane biomass residue successfully used for other processes. Due to several public policies implemented at the beginning of the 2000s, bagasse has become the main resource for power generation in sugarcane mills [12], allowing this traditional agricultural sector to gain a position as an important supplier of electricity to the national grid. This significant economic application has greatly increased the residue's economic value, while potential alternative applications have been developed over the past years. Hence, Carpio and Souza (2017) [13] proposed the use of the Modern Portfolio Theory [14] to assess optimal economic destinations for the surplus bagasse, considering the trade-off risk-profit.

In fact, the Portfolio Optimization Model [14] has been broadly used in several sectors to assist economic decision-making [15,16], such as in the agricultural sector [17], in environmental management [18,19], and in the sugarcane sector [20]. The variance is used as the measure of risk for financial assets in the portfolio. However, one difficulty with this model is that it penalizes negative and positive deviations identically. Thereupon, Rockafellar & Uryasev (2000) proposed a model that presents an asymmetric measure, the Conditional Value at Risk (CVaR), which satisfies the subadditivity property [21]. Among its other verified properties, the convexity and monotocity should be highlighted. Thus, it may be an adequate and coherent risk measure for portfolios [22].

To the best of our knowledge, there is no study in the literature that assesses the possible economic impacts of the insertion of biogas into the product portfolio of sugarcane mills. Although a few authors have examined the economic feasibility of such projects [11,23,24], they do not take financial risks into account in their analyses. In the sugarcane industry, price volatility plays an important role in decisions of product mix and, hence, may not be neglected. In general, production decision-making in the sector is based on price estimates for ethanol, sugar, electricity and diesel at the beginning of the season. Therefore, portfolio diversification through different applications of biomass may be a strategy to address the price volatility associated with the other traditional products.

This paper aims to contribute to studies in the sector by analyzing the economic impacts of biogas insertion in the product mix of sugarcane mills (ethanol, sugar, and electricity). For this, a portfolio model was developed respecting all operational constraints, where CVaR is the risk measure to be minimized. Furthermore, as uncertainties in the market and price volatilities may impact negatively on decisions, as a novelty for this approach, the use of robust optimization techniques [25–27] was proposed to mitigate the consequences of such price variations.

2. The sugarcane industry in Brazil

2.1. The production cycle

Nearly 30% of the total production cost in sugarcane mills located in the state of São Paulo is related to harvest and transportation [28]. Consequently, the development of new technologies and alternatives for such cost reductions are critical for this sector's economic progress. Among the main factors in transportation costs, fuel is especially important. In the sugarcane industry, diesel is the most-used liquid fuel. Therefore, an alternative energy source may be a promising opportunity for cost reductions.

In addition to harvest and transportation, the production process of a typical mill in the sugarcane sector can be divided into three main processes: the milling, the processing of sugar and ethanol, and power generation [29]. In this work, a fourth process step will be considered, although it is still experimental at most mills: biogas production. This sub product may have two destinations, electricity generation or diesel substitution for trucks in the harvest areas. All processes, feedstocks and products of a typical mill are summarized in Fig. 1. The process and the relationships represented in the figure will guide the development of the model proposed for the industry.