Sugarcane Supply Chain in the Brazilian Midwest Region

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The sugarcane supply chain is one of the main contributors to economic development in many countries. However, it is necessary to consider the relationship of this supply chain with the environment in order to reduce/mitigate adverse environmental impacts. Using fertilizers and pesticides and burning crops during harvest severely threaten the sustainability of this supply chain.

Keywords: sugarcane supply chain ; ethanol ; sustainability

1. Introduction

Even though the high consumption of fossil fuels has led to rapid economic growth in various segments of the economy, this energy source threatens the environment due to increased emissions of CO_2 and other polluting agents to the atmosphere [1].

Increased energy demand and growing awareness of climate change hazards from greenhouse gas (GHG) emissions caused by fossil fuels have raised interest in biomass energy production, resulting in significant growth in biofuel production [2].

According to Gilani, Sahebi, and Oliveira [1], policymakers and companies will support renewable energy sources (bioenergy and biofuels) and cleaner technologies as the pressure for cleaner and more sustainable energy generation increases. In this scenario, the authors highlight biomass as a sustainable energy source due to its wide range of primary resources and low production costs.

Sugarcane is one of the primary sources of renewable energy production. Due to the advantages of using biomass in generating renewable energy, many researchers have studied its applications [3][4][5][6]. According to Gilani, Sahebi, and Oliveira [1], bioethanol is the most developed renewable fuel. The authors assert that bioethanol from sugarcane presents high potential as a growing alternative to the consumption of fossil fuels. In addition, sugarcane bioethanol can contribute to reducing GHG emissions. However, despite its benefits, Bordonal et al. [7] state that Brazil's sugarcane production increase in recent decades has been associated with negative impacts on sustainability, especially concerning the environmental impacts of agricultural inputs and production processes of its supply chain.

As a result, the search for strategies to improve the sustainability of the sugarcane supply chain has become of utmost importance. According to García et al. [5] and Fang, Heijungs, and Snoo [8], one way to achieve this objective is by reducing GHG emissions. Many researchers highlight the life cycle assessment (LCA) method as a strategy for estimating the environmental impacts of a production process. De Figueiredo et al. [9] evaluated the carbon footprint of sugar production. Khatiwada and Silveira [10] analyzed emissions from ethanol production and electricity cogeneration. Renouf, Pagan, and Wegener [11] compared the environmental impacts of producing different sugarcane products. Other studies have addressed the sugarcane supply chain by exploring the LCA method in different contexts [3][4][6][12][13][14]. Despite researchers' efforts, few studies have analyzed the environmental and human health impacts of the sugarcane supply chain.

2. Brazilian Sugar and Ethanol Industry

Agriculture is an important economic activity in many countries [15]. According to the Brazilian Agriculture and Livestock Confederation (CNA) [16], in 2020, agribusiness output reached 27% of the Brazilian GDP. Among the segments of Brazilian agribusiness, the largest share belongs to the agricultural branch (70% of the sector).

Santoro, Soler, and Cherri [17] argue that sugarcane cultivation is essential for many countries' economies, especially Brazil. Machado and Da Cruz [18] present a list of the significant sugarcane producer countries and show that Brazil is the largest sugarcane producer in the world. According to the Brazilian National Supply Company (CONAB) [19], the sugarcane industry has been relevant to Brazil since the colonial period. Carlucci et al. [20] argue that sugarcane is responsible for a large portion of the Brazilian economy, generating income through the production of biofuels, sugar, ethanol, and distilled beverages. Furthermore, Carlucci et al. [20] assert that Brazil has the largest area of sugarcane cultivation globally, being the second-largest producer of ethanol and one of the world's largest consumers of this renewable energy. Gonçalves et al. [21] claim that there are more than 350 sugarcane mills in Brazil, generating jobs for the population and valuable products for society.

Brazil is renowned as a prominent technological and productive sugarcane biofuel producer, contributing to the emerging low-carbon economy and fostering global demand for alternative and renewable energy sources [22][23][24]. According to ÚNICA [25], Brazilian sugarcane ethanol represents 13.8% of the world's renewable energy matrix. Moreover, sugarcane ethanol is the biofuel with the lowest carbon footprint and with high energy efficiency [25]. According to Kota et al. [26], sugarcane is a potential source of renewable, low-cost energy that can be used as an alternative to conventional fuel and to reduce environmental pollution and dependence on fossil fuels.

3. Sugarcane Supply Chain Sustainability

According to Murphy and McCarthy [27], renewable sources are essential because they generate lower CO_2 emissions than traditional fuels, such as coal, oil, and natural gas. Jonker et al. [2] mention that the increase in energy demand and the growing awareness of climate change due to GHG emissions related to fossil fuels have increased the interest in using biomass to generate clean energy. Nie et al. [28] highlight that compared to other bioenergy sources, energy crops are suitable for large-scale commercial applications. According to Khatiwada et al. [12] and Rentizelas et al. [29], the existing biomass stock is sufficient to meet Brazil's demand for renewable energy sources.

Cavalcanti, Carvalho, and Da Silva [30] argue that renewable resources, such as biomass or waste, represent one of the strategies to reduce environmental impacts associated with energy generation. The use of sugarcane as bioenergy has been addressed by several researchers [1][2][28][31][32][33][34].

According to Lamers et al. [35], the global production of biofuel is dominated by ethanol, mainly in the United States of America (USA) and Brazil. Mozaffari, Ostovan, and Wanke [36] state that a sustainable supply chain is created by the feedback between sustainability dimensions, mainly related to environmental, economic, and social spheres. Mota et al. [37], Neutzling et al. [38], and Chavez et al. [39] highlight that achieving sustainability within the supply chain is still one of the challenges to be overcome.

4. Life Cycle Assessment (LCA) of the Sugarcane Supply Chain

According to Chavez et al. [39], Higgins [40], and Kadwa and Bezuidenhout [41], the sugarcane supply chain is composed of several activities, including cultivation, harvesting, transport, industrial processing, and distribution. Chavez et al. [39] state that a supply chain comprises a network of organizations, ranging from the initial provider (raw material producer) to the final consumer. Walters and Lancaster [42] argue that the main objective of supply chains is to add value to stakeholders, whether they are entrepreneurs or field workers. In this context, a prominent approach used to analyze the sustainability aspects of a supply chain is the LCA method.

LCA is a proper, standardized method, based on ISO 14040 and ISO 14044, to estimate the environmental impact of processes and products [5]. García et al. [5] and Khatiwada and Silveira [10] argue that the LCA method can measure a product's total environmental performance from the cradle to the grave.

LCA evaluates the potential environmental impact of products and services in a supply chain, gathering inputs and outputs of a product system and employing an impact assessment step [22]. García et al. [5] point out that this method has been widely used to identify products with lower environmental impacts or locate the production stages where the most significant environmental impacts occur in a supply chain.

Several studies have used LCA to identify the environmental impacts of different supply chains, such as bioelectricity [43][44][45][46][47]; sugar production [5][48]; ethanol production [4][10][49][50]; sugarcane products [6][11][51]; the agri-food chain [52][53]; and other products [13].

The sugarcane supply chain is constantly examined at strategic, tactical, and operational levels to obtain methods to improve its production. However, despite the economic importance of sugarcane and the different practices related to the growth and development of this market, numerous aspects must be considered throughout the supply chain to achieve sustainable development [1].

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