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Life cycle assessment of bioethanol production from cattle manure

Amaro de Azevedo [a], Franccesca Fornasier [b], Mateus da Silva Szarblewski [b], Rosana de Cassia de Souza Schneider [a, b, *], Michele Hoeltz [a], Diego de Souza [a]

[a] Environmental Technology Postgraduate Program, Santa Cruz do Sul University, Santa Cruz do Sul, Rio Grande do Sul, CEP 96815-900, Brazil
[b] Chemistry and Physics Department, Santa Cruz do Sul University, Santa Cruz do Sul, Rio Grande do Sul, CEP 96815-900, Brazil

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Biofuels can contribute significantly to reducing environmental damage. Lignocellulosic bioethanol can be an alternative to fossil fuels and is of great strategic importance to Brazil. In this context, the life cycle assessment (LCA) of bioethanol production from cattle manure (CM) was studied. CM is a biomass rich in cellulose that can be converted to glucose and other fermentable sugars. In the LCA, 1000 kg of CM were used as a functional unit of processing. The ReCiPe method and the EcoInvent libraries were used in SimaPro software version 7.3.2. We considered the following categories of impact: climate change, ozone depletion, terrestrial acidification, freshwater eutrophication, marine eutrophication, human toxicity, photochemical oxidant formation, particulate matter formation, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, ionizing radiation, agricultural land occupation, urban land occupation, natural land transformation, water depletion, mineral resource depletion and fossil resource depletion. The categories damaged were human health, ecosystems and natural resources. The results obtained in the life cycle impact assessment (LCIA) and the proposed changes in the process contributed to the reduction of environmental impacts. The inputs/outputs that made the greatest contribution to environmental impacts were energy consumption, drying emissions, sulfuric acid in the pretreatment, buffer in the enzymatic hydrolysis and sodium phosphate in the fermentation. Bioethanol production from CM has a low impact on most of the categories and is a process that can be improved to reduce its impact mainly by changing the energy type. In the LCIA, it was observed that the CM bioethanol production eliminates the need for disposal treatment of the manure and uses residual raw material in a biofuel production, thus counterbalancing the environmental impacts of the bioethanol process.

1. Introduction

The energy scenario has been facing a crisis due to the indiscriminate extraction and abundant consumption of fossil fuels, which has led to fossil fuel depletion and environmental degradation. This situation has stimulated the search for alternative fuels characterized as non-fossil, renewable, and non-polluting (Agarwal, 2007). Lignocellulosic biomass is known as a source of clean energy, and low-carbon biofuels are an important element in bioenergy development (Borrion et al., 2012).

Over the past 20 years, bioethanol has been one of the leading candidates to replace a fraction of the liquid fuels produced from oil and has become prominent in the conversion of biomass resources for the production of biofuels (Megawati et al., 2011). Bioethanol can be used in engines specially designed for its use. However, it can also be used in mixtures of up to 10% with gasoline without engine modifications or in a greater proportion (85%) in flexi-fuel vehicles (Hamelinck et al., 2005; Kumar and Murthy, 2011). The main sources worldwide for ethanol production are materials rich in sugar and starch. The USA and Brazil produce ethanol from corn and sugar cane, respectively, while in Europe and in China, cereals are used as raw materials (Morales et al., 2015). With 89% of the total production, the USA and Brazil are the main producers of bioethanol in the world (Limayem and Ricke, 2012). Although it has been a promising substitute for gasoline, this biofuel production only replaces a minimal portion of the worldwide consumption of fossils fuels.

However, land use issues and threats to food security have made biofuel production controversial, mainly due to the uncertainties of the environmental benefits and the social disadvantages (Paschalidou et al., 2016).

* Corresponding author. Environmental Technology Postgraduate Program, Santa Cruz do Sul University, Santa Cruz do Sul, Rio Grande do Sul, CEP 96815-900, Brazil.

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Alternatively, using waste as raw material may be a more promising option for biofuel production (Nasterlack et al., 2014) because the first-generation biofuels require the growth of food. To be sustainable, value chains of biomass to bioenergy products require the successful deployment of innovative biotechnologies.

Residual biomasses, such as agro-industrial byproducts and residues and animal manures, represent the spatially diffused sources of biofuel substrates. In the agro-industry there is a wide variety of organic feedstock, such as lignocellulosic materials, vegetable oils, animal fats, protein-rich waste, animal slurries and manure (Schievano et al., 2009).

Lignocellulosic biomass has received special attention in biofuel production because of concerns over high fuel prices, energy supplies, global climate change, and diversification for rural economic development (González-García et al., 2013). Moreover, according to González-García et al. (2012) second-generation biofuels derived from lignocellulosic biomass are environmentally attractive in terms of biomass exploitation, such as wood and agricultural waste. Cost-effective sources of energy are important because production technology is still under development.

Recently, several studies assessed the environmental performance of the production and use of cellulosic bioethanol (e.g., eucalyptus (González-García et al., 2012), black locust (González-García et al., 2011), wheat (Biswas et al., 2008), switchgrass (Morales et al., 2015), straw (Kravanja et al., 2012) and grass straws (Kumar and Murthy, 2012)). The main objective was to compare the environmental impact of bioethanol produced from lignocellulose and by the most diverse production methods. The most commonly used approach is the life cycle assessment (LCA), which is a methodological tool used to quantitatively analyze the life cycle of a product or an activity within a generic frame provided by ISO:14040 (2006) and ISO:14044 (2006).

Many bioethanol production paths have already been evaluated using LCA tools as presented in Table 1. In these studies there is a focus on the determination of global warming potential, which is established from the amount of CO_2-eq of all stages of production. The results demonstrate the concern with the type of biomass to be transformed, with the process and with the possibility of this liquid fuel being responsible for impact reduction attributed to the use of fossil fuels. However, the use of residues as feedstock for biofuel is still excipient, and there are no studies that evaluate the impacts of using animal residues with high fiber content convertible to sugars and ethanol.

LCA studies have also been conducted from cellulosic material in general, which is acceptable, because the transformation methodology is sufficiently robust.

Without large-scale production, the potential environmental performance of many proposed procedures remains unclear. Therefore, the LCA tool allows the identification of potential impacts in an initial phase of the design process and provides the opportunity for decision-making to improve the process for sustainability before it is scaled up or fully implemented. As in Table 1, there is process optimization and interest in demonstrating that it is environmentally friendly.

In this way, many efforts have been made in the last decades to develop a commercial process for producing second-generation bioethanol using lignocellulosic biomass (Cardona et al., 2010), which combines both economic and environmental factors.

One example is the large pollutant load that is not properly managed from the waste generated by feedlot cattle. If these residues reach water sources, they will increase the chemical oxygen demand, reduce the oxygen content of the water and, finally, cause the death of fish and other organisms. Furthermore, the presence of nutrients such as N, P and K stimulates the growth of aquatic plants, which may cause water eutrophication. Cattle manure (CM) contains undigested lignocellulosic material, the composition of which depends on the diet and can be easily separated in confined systems. Overall, cattle convert only 30%–40% of the ingested food in production (Kozen and Alvarenga, 2005).

Generally, the final destination of manure is lagooning, direct application to land, composting, anaerobic digestion or combustion, all of which have environmental impacts related to CH_4, N_2O and NH_3 emissions. In combustion the only problematic emission is N_2O (Sagastume Gutiérrez et al., 2016). However, there is already an established market for biogas production by anaerobic digestion that is successful for energy production as more energy efficient technologies come into use (Fuchsz and Kohlheb, 2015). Thus, manure is a little-explored reservoir of biomass for energy production, such as ethanol (Liao et al., 2014).

Because production cost is extremely sensitive to biofuel feedstock costs, waste can be an alternative to feedstock with high starch or sugar content; however, challenges such as biomass transport and handling and difficulties within the process must be considered (Bhutto et al., 2015). In addition to developing a technological framework, it is important to consider the emissions and inputs required to achieve the maximum process efficiency.

Based on aspects of the production of bioethanol from lignocellulosic biomass, the main objective of this study was to apply the LCA to the production of cellulosic bioethanol from CM. For this purpose, the process was examined at the laboratory scale using parameters that have already been optimized by (Vancov et al., 2015). The data were organized according to the process established in Vancov et al.'s study with Australian cattle manure and conducted on the laboratory scale with cattle manure from the south of Brazil, and the Evaluation of the Life Cycle was performed using *Simapro software 7.3.2*.

Following the research mentioned above, the present study was designed to enhance the insight into environmental performance of bioethanol from CM by applying LCA as a support for decision making in the context of green chemistry and eco-innovation strategies.

2. Methodological approach

LCA is a compilation and evaluation of the inputs, outputs and the potential environmental impacts of a process or product system throughout its life cycle. A product or process causes impacts on its ecosystem, during production, distribution, consumption, disposal and recycling (ISO-14040, 2006). LCA includes the following steps: Goal and scope definition, Inventory analysis, Impact assessment and Interpretation, all of which were followed in this work.

The life cycle assessment method was used to evaluate the environmental impacts of all stages of CM bioethanol production. The research was initially performed on a laboratory scale from August 2013 to December 2014. The equipment selected for the pilot configuration for CM bioethanol production was equipment that is commonly used for several biomass preparations and transformations and can be found in the domestic market. The equipment had the characteristics, size, power consumption and other necessary attributes for assessment. The procedure proposed for the production of bioethanol was Separated Hydrolysis and Fermentation (SHF) using previously optimized conditions. The Life cycle impact assessment (LCIA) was carried out before the installation of equipment. This tool was used for support decisions about the stages and care of lignocellulosic bioethanol production. The procedures to assess the environmental impacts of CM bioethanol production have been further detailed.

2.1. Goal and scope

The goals were to evaluate the potential environmental impacts