# LIFE CYCLE ASSESSMENT OF BIOETHANOL PRODUCTION FROM SWEET POTATO WASTE

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## ABSTRACT

This work investigated a comparison between acid and enzymatic starch hydrolysis for bioethanol production from sweet potato waste. The results revealed that enzymatic hydrolysis has lower impacts. For the six impact categories investigated, the main contribution came from sweet potato crop plantation, ranging from 74 to 87 %, followed by electricity use, ranging from 9 to 17%.

**Keywords:** sweet potato, starch enzymatic hydrolysis, acid enzymatic hydrolysis, bioethanol, life cycle assessment.

## 1 INTRODUCTION

Sweet potatoes (SWP) are highly nutritious tuberous roots with various health benefits. They are rich in vitamins A and C and several B vitamins, including B6. They also contain minerals like potassium, manganese, and copper. The primary macronutrient in sweet potatoes is carbohydrates, with a significant portion being dietary fiber. They contain various antioxidants, including beta-carotene, which is converted into vitamin A in the body. While sweet potatoes contain some protein, they are not considered a high-protein food source.

In 2022, Rio Grande do Sul was the second producer of sweet potatoes in Brazil, with around 155,000 t, contributing 18.3 % of Brazilian production[1] . However, according to Mussolini et al.[2] the cull rate could reach 36%, considering current USDA definitions. It presents an opportunity to enhance biofuels production in Rio Grande do Sul using wasted sweet potato as raw material. The GIMSCOP research group has studied the conversion of sweet potatoes (residue) to ethanol [3,4], flour[5], distilled beverages [6] and leaves tea production. Both acid and enzymatic hydrolysis were studied, with enzymatic being more cost-effective. This work aims to compare both processes from an environmental point of view using the Life Cycle Assessment (LCA) methodology.

## 2 MATERIAL & METHODS

<u>Acid hydrolysis</u>. Fresh SWP was mixed with HCl 1% v.v$^{-1}$ in the 1 kg dry SWP:10 L proportion. The samples were heated at 121°C for 10 min. Neutralization was done with 10% NaOH solution (w.v$^{-1}$) until pH 4.5. 3.33 mg g$^{-1}$SWP of *Saccharomyces cerevisiae* was added for cultivation at 35°C for 18 h.

<u>Enzymatic hydrolysis</u>. It was based on the work of Carvalho, Trierweiler and Trierweiler [3,4]

<u>LCA</u>. The LCA calculations have been performed using openLCA 2.1.0 (https://openlca.org). The data for sweet potato crop production was based on EMBRAPA studies [7]. The complete Inputs and Outputs for sweet potato crop production and bioethanol are presented in **Table *1***. The yeast production was modeled according to Maga et al. (2019)[8]. The datasets used for modeling were taken from the GREET[10] model, developed by Argonne National Laboratory, and the LCA Collaboration Server (NAL)[11].

**Table 1**. Inventory for sweet potato crop production, acid, and enzymatic hydrolysis.

| Sweet potato crop production | | | |
|---|---|---|---|
| Input | Unit | Output | Unit |
| Fertilizer, $K_2O$ | 154 kg | Sweet Potato | 20 t |
| Fertilizer, N | 76 kg | Nitrogen Oxides | 1.46 kg |
| Fertilizer, $P_2O_5$ | 195 kg | | |
| Electricity | 2206 kWh | | |
| Bioethanol production via acid hydrolysis | | | |
| Electricity | 169.87 kWh | Ethanol | 265 kg |
| Hydrochloric Acid | 196.81 kg | Carbon dioxide | 281 kg |
| Sodium Hydroxide | 52.12 kg | | |
| Sweet Potato | 5956.75 kg | | |
| Water | 14922.5 L | | |
| Bioethanol production via enzymatic hydrolysis | | | |
| Electricity | 123.98 kWh | Ethanol | 265 kg |
| Alpha-Amylase | 0.596 kg | Carbon dioxide | 281 kg |
| Gluco Amylase | 1.657 kg | | |
| Sweet Potato | 2804.1 kg | | |
| Yeast | 9.25 kg | | |
| Water | 1955.63 L | | |

Life Cycle Impact Assessment (LCIA). Recipe 2016 Midpoint (H) was the Impact Assessment Method, applying World (2010) H for normalization and weighting set.

## 3 RESULTS & DISCUSSION

**Table *2*** presents the Life Cycle Impact Assessment (LCIA) normalized acid and enzymatic hydrolysis results. For all impact categories, acid hydrolysis presented a higher impact than enzymatic hydrolysis. The highest impacts are distributed among toxicity categories: marine ecotoxicity, freshwater ecotoxicity, human carcinogenic toxicity, human non-carcinogenic toxicity, and terrestrial ecotoxicity. Therefore, the following analysis will be presented for those five categories, with the addition of Global Warming.

For each impact category, the contribution of the inputs was assessed. Generally, the largest share corresponds to sweet potato production, followed by electricity, yeast, and enzyme production, as shown in **Erro! Fonte de referência não encontrada.** (a). In particular, electricity and fertilizers are mainly responsible for the high impact of sweet potato cultivation (**Erro! Fonte de referência não encontrada.** (b)). The impact assessment of bioethanol production from sugarcane in Brazil also revealed that the main contribution in several impact categories came from the agricultural stage. The two main contributions to acid hydrolysis are sweet potato production and electricity use. Like enzymatic hydrolysis, the main contributions in sweet potato cultivation are using electricity and fertilizers, which are slightly higher for the latter (Figure 1 c and d). Regarding Global Warming potential, 0.702 kg CO2eq and 0.1283 kg CO2eq are emitted per 1 kg of bioethanol produced, even considering the biogenic production of CO2 during the fermentation. The main contributions come from the use of electricity, both direct (17.21%) and indirect (plantation and harvesting, 42,93%), and fertilizers (31,93%).

It is important to note that bioethanol will be produced from sweet potatoes that would otherwise be discarded; unlike sugarcane, sweet potatoes are mainly cultivated and harvested to supply human food. The proposal is to use potatoes not marketed for ethanol production. Thus, although the impact of sweet potato cultivation is being evaluated, it would already exist regardless of whether it is destined for human food or biofuel production.

**Table 2**. LCIA normalized results for acid and enzymatic hydrolysis

| Impact category | Acid Hydrolysis | Enzymatic Hydrolysis |
|---|---|---|
| Fine particulate matter formation | 0.09593 | 0.05033 |
| Fossil resource scarcity | 0.38528 | 0.19923 |
| Freshwater ecotoxicity | 30.4364 | 15.51589 |
| Freshwater eutrophication | 0.85204 | 0.42655 |
| Global warming | 0.16067 | 0.08798 |
| Human carcinogenic toxicity | 13.24242 | 6.86106 |
| Human non-carcinogenic toxicity | 7.76709 | 3.92188 |
| Ionizing radiation | 0.23395 | 0.12284 |
| Land use | 0.0107 | 0.00716 |
| Marine ecotoxicity | 49.90112 | 25.42632 |
| Marine eutrophication | 0.01066 | 0.00558 |
| Mineral resource scarcity | 0.00142 | 0.00067 |
| Ozone formation, Human health | 0.18146 | 0.0957 |
| Ozone formation, Terrestrial ecosystems | 0.21246 | 0.11209 |
| Stratospheric ozone depletion | 0.04089 | 0.02167 |
| Terrestrial acidification | 0.15712 | 0.08199 |
| Terrestrial ecotoxicity | 2.90411 | 1.49055 |
| Water consumption | 0.55997 | 0.1818 |

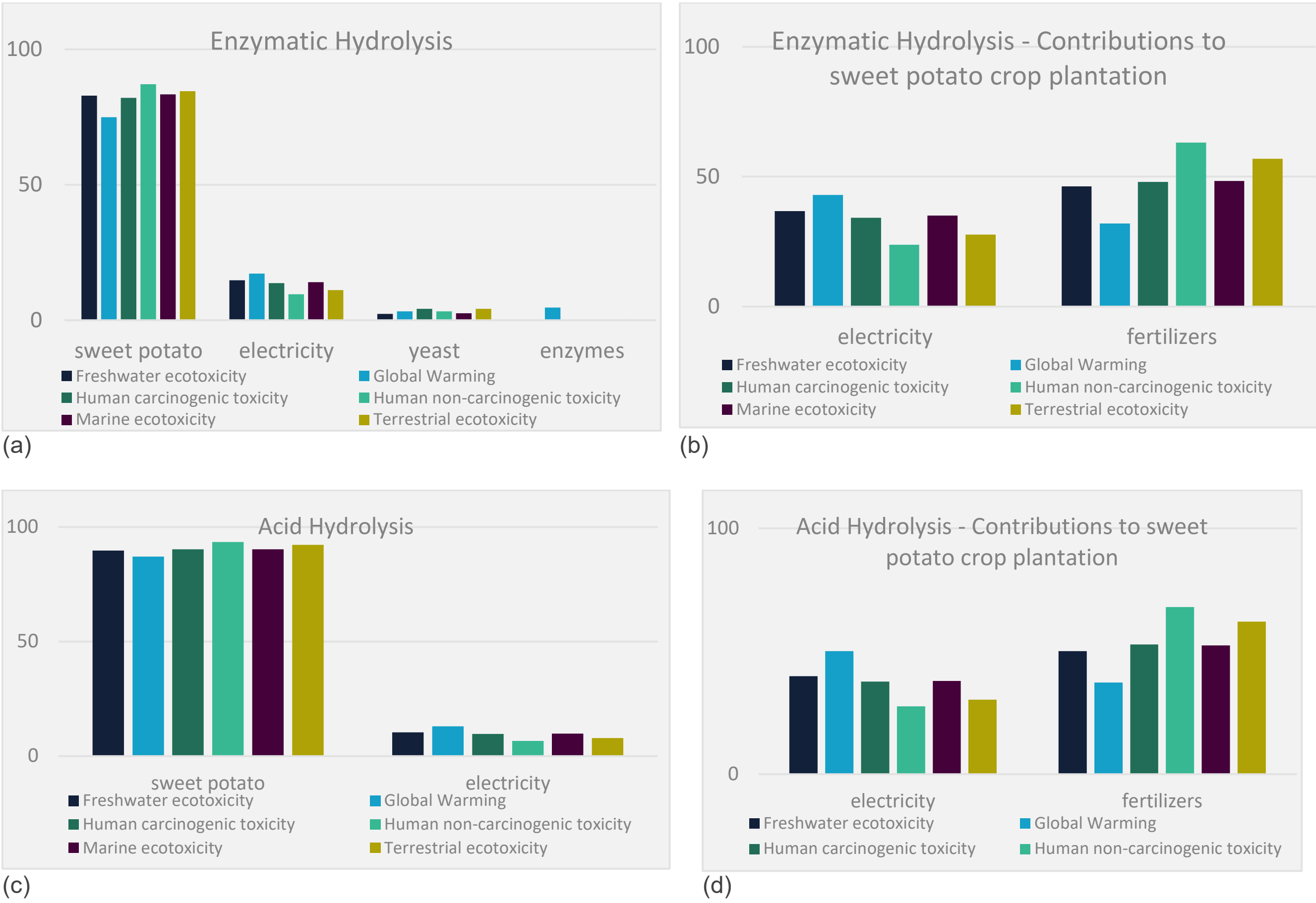


*Figure 1. Input contributions for bioethanol production with enzymatic hydrolysis and acid hydrolysis*

## 4 CONCLUSION

The results showed that to produce ethanol from sweet potato residues, the best from an environmental point of view, is to use enzymatic hydrolysis since the environmental impacts were lower in all categories analyzed.

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