Life cycle analysis of hydrogen production by gasification of eucalyptus and natural gas in the brazilian context

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ABSTRACT

AA life cycle assessment (LCA) approach was applied to compare hydrogen production via natural gas steam reforming with eucalyptus biomass gasification under Brazilian conditions. This study analyzed the environmental impacts of producing 1 kg of hydrogen in three scenarios: i) S1H_2 – grey hydrogen, ii) S2H_2 – blue hydrogen (with CCS), and iii) S3H_2 – hydrogen from eucalyptus biomass gasification. Using the ReCiPe midpoint (H) method to assess nine impact categories, the results show that the S1H_2 and S2H_2 scenarios generate 17.5 kg and 12.9 kg of CO_2 equivalent emissions, respectively, while the S3H_2 scenario emits just 0.804 kg of CO_2 equivalent (CO_2 eq.), representing a reduction of approximately 95% compared to the S1H_2 scenario. These findings indicate that replacing fossil fuels with eucalyptus biomass in hydrogen production can lead to significant reductions in greenhouse gas emissions, making biomass gasification a promising alternative for sustainable hydrogen production under the right conditions.

Keywords: Hydrogen production; technoeconomic assessment; environmental impact; CO_2 capture and storage.

INTRODUCTION

In Brazil, the predominant production of hydrogen comes from the steam reforming of natural gas, used mainly in refineries and fertilizer industries. However, there is a growing search for sustainable alternatives, such as green hydrogen, produced by electrolysis of water using renewable energies. This type of hydrogen is considered the cleanest and most sustainable. In contrast, grey hydrogen, derived from fossil fuels, has a high environmental impact, while blue hydrogen, also produced from fossil fuels, uses CO_2 capture to reduce its emissions.

The gasification of biomass, such as eucalyptus, has emerged as a promising alternative in Brazil. This process transforms biomass into synthesis gas, which can be reformed to obtain hydrogen. The use of eucalyptus, an abundant plant in the country, not only offers a renewable source of hydrogen, but also contributes to environmental and economic sustainability by utilizing agricultural and forestry waste.

Life Cycle Assessment (LCA) is a fundamental tool for analyzing the environmental performance of different hydrogen production technologies throughout their life cycle. The aim of this study was to analyze and compare the potential environmental impacts involved in hydrogen production technology via natural gas reforming and Eucalyptus gasification, using the life cycle assessment methodology in the Brazilian context.

MATERIALS AND METHODS

The study followed the life cycle assessment methodology, using the Simapro 9.5.0.0 software developed by PhD with Share & Collect ©Pre Sustainability 1990-2023 to calculate the impacts following the phases prescribed by the ABNT NBR ISO 14040 and 14044 standards.

Definition of objective and scope

The aim of this study is to analyze and compare the potential environmental impacts involved in hydrogen production technology through the steam reforming of synthesis gas under Brazilian conditions, and to identify potential further improvements in the three scenarios: grey hydrogen (S1H2), blue hydrogen (S2H2) and eucalyptus gasification (S3H2). The function of hydrogen is to serve as an energy source to produce heat and electricity. In this case, the Functional Unit (FU) was defined as 1 kg of hydrogen produced. A cradle-to-grave system boundary was used, including the life cycle phases of raw material production, manufacturing, including processes that take place outside Brazil before purchase, and end-of-life. The consumer use phase, infrastructure processes and long-term emissions were excluded from the analysis.

Analyzing the inventory

The data used to calculate the life cycle inventory was collected from different sources as illustrated in Table 1, with details of all the inputs (such as raw materials, energy, water) and outputs (such as atmospheric emissions, liquid effluents, solid waste) throughout the life cycle of the product or activity and incorporated into the SimaPro ® 9.5.0 software database.

Table 1: Main sources consulted.

Inventories	Sources
Natural gas	(Capaz *et al.*, 2020)
Biomass	(Alves *et al.*, 2024)
$S1H_2$ e $S3H_2$	(Hren *et al.*, 2023)
$S2H_2$	(Duval-Dachary *et al.*, 2023)

Life Cycle Impact Assessment (LCIA)

For this study, the categories were compared using the ReCiPe midpoint (H) method, following the methodology used by Weidner, Tulus and Guillén-Gosálbez, (2023), using the normalization approach for the categories with the greatest LCIA impact. The impact categories calculated include global warming (GW), mineral resource scarcity (MRS), land use (LU), stratospheric ozone depletion (SOD), marine eutrophication (ME), human non-cancer toxicity (HNCT), ionizing radiation (IR) and water consumption (WC).

RESULTS AND DISCUSSION

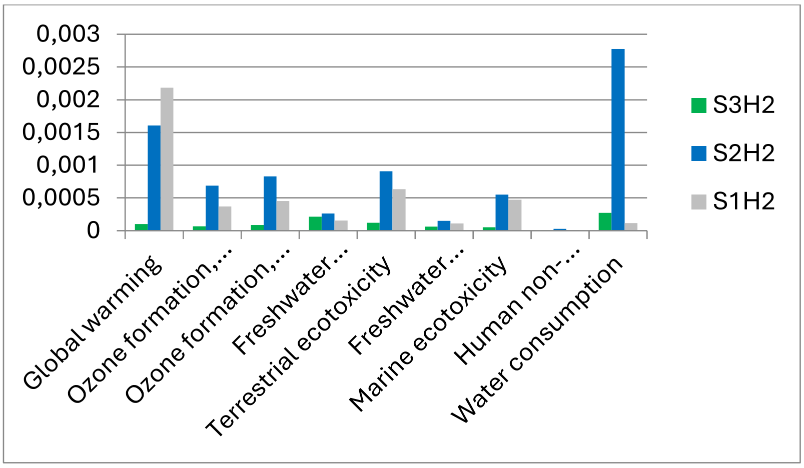

Figure 1. Comparison results of the LCIA of producing 1 Kg of hydrogen in the Brazilian context: Normalization

The normalized results shown in Figure 1 highlight the variations in environmental performance between the three scenarios, with some indicating higher impacts in specific categories, such as water consumption (WC) and global warming (GW). The normalization shows that while the $S2H_2$ scenario presents a reduction in greenhouse gas emissions due to CCS, it also demonstrates a significant impact on the consumption of water resources. In contrast, the $S3H_2$ scenario, which uses eucalyptus biomass, stands out for its lower greenhouse gas emissions, but still faces challenges in these categories due to the use of fertilizers and electricity.

Antonini et al., (2020) considers from a life cycle point of view, the addition of CCS with clear benefits with regard to impacts on climate change, due to the greater capture of CO_2, despite a worse performance than without CCS in relation to other environmental loads as a result of increased energy consumption.

Table 2. Characterization of impacts for all scenarios

IC	Unit	$S3H_2$	$S2H_2$	$S1H_2$
GW	Kg CO_2 eq.	0,804	12,9	17,5
OFHH	Kg Nox eq.	0,00133	0,0142	0,00766
OFTE	Kg Nox eq.	0,00152	0,0147	0,00807
FE	Kg P eq.	0,00014	0,000171	0,0001
Fec	Kg 1,4-DCB	0,00159	0,00379	0,00283
Mec	Kg 1,4-DCB	0,00236	0,024	0,0206
HNCT	Kg 1,4-DCB	0,00396	0,0292	0,0154
Tec	Kg 1,4-DCB	1,87	13,8	9,65
WC	m^3	0,072	0,74	0,0305

The results (Table 1) indicate that the $S3H_2$ scenario, which during the production process involves the use of eucalyptus biomass that absorbs carbon dioxide from the atmosphere during growth, outperforms the fossil fuel-based scenarios ($S1H_2$ and S_2H3) in most impact categories, with the exception of eutrophication (FE) and water consumption (WC). However, the use of water, fertilizers and agrochemicals during the eucalyptus cultivation stage in the $S3H_2$ scenario, as well as the supply of electricity from nonrenewable sources, contribute to a greater release of nutrients, impacting the eutrophication process.

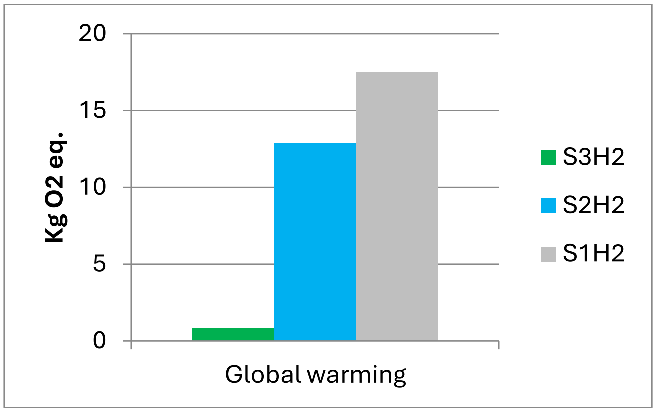

Figure 2. Comparison of global warming potential to produce 1 Kg of hydrogen in the Brazilian context.

As shown, compared to the three scenarios, the S2H_2 technology has significantly greater impacts in all categories due to the greater use of energy and solvents in the CCS process. However, a 26% reduction in emissions in the global warming category stands out, surpassing the S1H2 scenario, which has total emissions of 17.5 kg of CO_2 equivalent. In contrast, the S3H2 scenario achieves approximately a 4.6% reduction in emissions, resulting in 0.804 kg of CO_2 equivalent, highlighting its comparatively lower environmental impact, with S2H2 emitting 12.9 kg of CO_2 equivalent.

During photosynthesis, eucalyptus sequesters carbon dioxide from the atmosphere, fixing and storing carbon in its biomass. In the S3H2 scenario, the use of eucalyptus biomass mitigates a significant portion of life cycle greenhouse gas emissions, demonstrating the potential of this feedstock to contribute to a lower carbon footprint in hydrogen production (Figure 2).

According to the authors Patel et al., (2024) the production of grey hydrogen results in 13% higher emissions on the LNG route, with 13.9 kg CO_2 eq, compared to 12.3 kg CO_2 eq on the pipeline route. On the other hand, blue hydrogen generates lower emissions than grey hydrogen thanks to the use of CCS, resulting in 7.6 kg CO_2 eq. per kg of H_2 on the pipeline route and 9.3 kg CO_2 eq. per kg of H_2 on the LNG route.

CONCLUSION

In this article, all the inputs and outputs involved in each hydrogen production process via steam reforming of $S1H_2$, $S2H_2$ and $S3H_2$ were thoroughly analyzed, and all the emissions for the 9 impact categories were calculated and then compared using the LCA methodology. The potential impacts of each method are quantified and in terms of total carbon dioxide equivalent emissions, the environmentally friendly scenario is $S3H_2$ (0,804 kg) because it is associated with the process of photosynthesis, which is responsible for CCS in eucalyptus biomass. The other scenarios, due to their fossil fuel sources, had greater impacts, with the $S2H_2$ scenario showing a 26% reduction in greenhouse gas (GHG) emissions. This is because it is associated with CCS technology, resulting in a potential clean energy carrier in the successful decarbonization scenario to respond to the Paris 2015 agreements, which call for a 7.6% reduction in global GHG emissions per year by 2030 to ward off the chance of collapse, stabilizing global warming at 1.5°C.

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