**Synergies between bioSAF production, and application of biochar in Brazilian crops**

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# Overview

With the increase in anthropogenic greenhouse gas (GHG) emissions, the world is currently facing a climate crisis. In response to this, 195 members of the United Nations committed to reducing their emissions under the Paris Agreement. In the transportation sector, where a significant portion of emissions occurs, there is a focus on replacing carbon intensive technologies with cleaner alternatives such as electric vehicles associated with solar and wind power, or biomass fuels where internal combustion is still used. Aviation has particular challenges due to its dependence on fossil fuels. This sector is hard to electrify and requires fuels to have high energy density and low specific mass, limiting low carbon approaches. To address this, the International Civil Aviation Organization (ICAO) has established the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), which includes as strategies the use of bio-based sustainable aviation fuels (bioSAF) and development of projects for carbon emission offsets.

When considering life cycle emissions and non-CO2 GHG, there is no bioSAF production with zero GHG emissions, which means carbon dioxide removal (CDR) would be needed to achieve net-zero using such fuels (Bergero et al. 2022; ICAO, 2022). Additionally, the use of biochar in soils has been considered as a form of CDR. Biochar, a carbon-rich solid produced from biomass via pyrolysis, has shown potential as solid storage of carbon removed by photosynthesis when applied to soils. Studies suggest biochar from bagasse sugarcane can sequester significant amounts of carbon, with estimates ranging from 1.8 to 6.3 t/ha and even higher at a global scale (Lefebvre et al. 2021). Another option is to use sugarcane straw to become biochar (Teixeira, 2023). Pairing biochar and bioSAF use in an integrated production system, may be possible, and potentially could result in a solution that combines carbon offsetting and reduction, achieving neutral emissions while providing agricultural benefits.

According to Conab data, the average sugarcane production for the 2021/2022 and 2022/2023 harvests was 594 million tonnes of sugarcane. This resulted in approximately 36 million tonnes of sugar and 27 billion liters of ethanol. With Brazil already established as a leading producer of sugarcane and ethanol, it demonstrates the country's potential to become a significant player in the Alcohol-to-Jet (ATJ) market. Brazil’s expertise in agriculture and biofuels, especially sugarcane, positions it strategically for such initiatives. Also, studies on biochar from sugarcane residues have demonstrated positive results in soil remediation, indicating its potential for broader environmental benefits.

Therefore, the aim of this study is to assess the climate mitigation benefits of jointly producing bioSAF and biochar from sugarcane. The evaluated pathway for the biofuel is ATJ, with its carbon intensity (CI) obtained from ICAO (2022). Biochar is evaluated in terms of its production potential and carbon dioxide removal capabilities using data from Conab (2023), Lefebvre at al. (2021) and Quirk et al. (2012). Finally, calculations are made to determine how the inclusion of biochar in the ATJ production process influences the mitigation potential of the studied bioSAF. Preliminary results suggest that for every MJ of ATJ produced, when using bagasse to produce biochar for CDR, the GHG offsetting is 66.1 gCO2eq. The ATJ production results in 24.1 gCO2eq/MJ (ICAO 2022), which represents a 74% mitigation compared to fossil jet fuel’s CI. When considering both the mitigation from ATJ and offsetting from biochar, liquid emissions are - 42 gCO2eq/MJ which is 147% less than those from using fossil jet fuel with no offsetting. To further improve analysis, future studies must address uncertainties such as biochar characteristics and types of soil combination as determinant factor for carbon removal potential.

**Methods**

This study is divided in four sections: (i) description of integrated production system, (ii) biochar yield, (iii) CDR estimation, (iv) integrated carbon offset and reduction.

First, the boundaries of an integrated system to jointly produce AtJ and biochar from sugarcane is designed. It is assumed that ethanol, currently used in light urban vehicles in Brazil, would be redirected to air transport. So AtJ production is considered to have similar characteristics to current Brazilian ethanol sector, such as sugarcane productivity, which is an average of 71.6 t/ha for the 2021/2022 and 2022/2023 crops (Conab, 2023). This sugarcane will be entirely directed to AtJ production, so there is no sugar being coproduced. On the other hand, all the bagasse resulting from the process is assumed to be intended for biochar production through pyrolysis.

Secondly, to estimate biochar yields, the bagasse fraction is needed. Lefebvre et al. (2021) suggested that sugarcane produces 10.4 t/ha of bagasse, so this was the value adopted. Furthermore, Lefebvre et al. (2023) indicates that 26% of bagasse mass is converted to biochar via pyrolisys process and one tonne of biochar applied into the soil can storage 0.638 tC which means 2.3 tCO2.

To estimate the total CDR due to biochar production and application, it was necessary to determine the amount of biochar yielding from the production of 1 MJ of ATJ. Using ICAO (2022) data is it assumed that ATJ yield (PATJ) is 1313 MJ per tonne of sugarcane. When combining this with data from Conab for sugarcane productivity (Psc) it is possible to estimate ATJ production in MJ per ha. Thus, dividing bagasse yields (Pbg) by this value, it leads to bagasse production in function of MJ of ATJ. With the conversion of 0.313 tonnes of biochar (tbc) for every tonne of bagasse (tbg) and carbon sequestration of 2.3 tCO2/tbc the resulting number represents CDR in gCO2/MJ of ATJ (Equation 1).

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Finally, the total liquid emissions resulting from the mitigation derived of using sugarcane ATJ and the offset from CDR using biochar produced in the integrated system designed are then compared to the carbon intensity (CI) of fossil jet fuel, of 89 gCO2e/MJ according to ICAO (2022). The purpose is to evaluate how integrating the bioSAF production with biochar production and use as CDR can provide advantages for reducing emissions from using fossil jet fuel.

# Results

The preliminary estimates suggest that utilizing sugarcane bagasse for biochar production, intended for soil amendment, could offer significant advantages in terms of ofsetting. In an integrated production system for every MJ of aviation biofuel produced about tonnes of biochar can be obtained. Since every tonne of biochar can storage the equivalent to 2.3 tCO2, the amount of offsetting is 66.1 gCO2eq/MJ. When considering that sugarcane ATJ life cycle emissions are 24.1 gCO2eq/MJ (ICAO, 2022) the production of this bioSAF alone mitigates 74% of the emissions from using fossil jet fuel, which are 89 gCO2eq/MJ. The biochar produced in the system can offset 74% of the fossil emission also. Nevertheless, if mitigation and offset are applied the liquid reduction of emissions is – 42 gCO2eq/MJ, equivalent to 147% less than those from using fossil jet fuel with no offsetting.

It is crucial to highlight a number of factors that can alter this result. For example, the emissions from collecting the bagasse applying pyrolysis and storing biochar in the soil where not accounted. The emissions from sugarcane production can also vary according to different regions (ANP, 2023). The potential of biochar to storage carbon depends, among other factors, on soil, humidity, temperature, clay content and mineralization rate. It is also depends on the characteristics of the feedstock, the temperature and durations of pyrolysis reaction and the amount of biochar applied (Zimmerman et al, 2011).

**Conclusions**

This study emphasizes the importance of biochar in CO2 sequestration, greenhouse gas emission reduction, and soil improvement. It was observed that jointly producing ATJ and biochar from sugarcane is possible and could provide benefits in terms of both offsetting and mitigation of GHG emission. However, it is essential to recognize associated uncertainties, such as variability in sugarcane ethanol carbon intensity and various factors affecting biochar capture potential, such as feedstock, pyrolysis conditions, soil humidity, clay content, among others (Zimmerman et al. 2011).

Furthermore, sugarcane bagasse is currently used in Brazil to generate the energy used in sugar and ethanol production. The exceeding energy is commonly converted into electricity and supplied to Brazilians grid (EPE, 2023). Sugarcane straw can also be used (Texeira, 2023) but some residual must stay in the fields to preserve the soil from erosion.

Thus, the result presented must be interpreted with discretion. Future research can explore different biochar uses and enhance understanding of these factors, contributing to more effective strategies in climate change mitigation and offsetting.