Estimating Surplus Pastureland for Bio-Based Sustainable Aviation Fuels Production in Brazil for 2050.

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Overview

Within the Paris Agreement goal to stabilize global warming to 1.5ºC/2ºC by the end of the century, the aviation sector in Brazil announced the goal of decarbonizing by 2050 (ANAC, 2022). Through the Fuel of the Future Program, the country highlights the role of sustainable aviation fuels made from biomass (bioSAF) such as sugarcane, soybean, and other alternative feedstocks that could be used in Alcohol-to-Jet (AtJ) and Hydrotreated Esters and Fatty Acids (HEFA) production routes. However, other bioenergy policies also consider Brazil's potential to provide biofuels, for example, policies to decarbonize maritime and road transportation (CEBRI, 2023). Thus, the overlapping demand for bioenergy resources might be considerable and increase the demand for land to cultivate sugarcane and soybean as feedstocks. With this, potential land use change (LUC) should be assessed to fully address decarbonization, as its emissions can be higher than those from fossil fuel burning (Fargione et al., 2008). However, releasing land through intensification of agriculture may avoid native vegetation suppression, which is the LUC with highest emissions. This study estimates the release of pastureland for bioSAF production in Brazil by 2050 and the LUC emissions for different regions in the country. Using projected demand for agricultural commodities (Fiorini et al., 2023) together with productivity data (IBGE, 2022), the total agricultural land for Brazil in 2050 was estimated. By designing scenarios of an improved cattle stocking density from 1.4 animal/ha to 2.0 animal/ha, pasture surplus area was estimated for agricultural expansion and for energy crops, without the need for native vegetation suppression. With the available land, bioSAF production was estimated using data from CORSIA (2022) and CONAB (2023). Direct LUC emissions were calculated using BRLUC data (2021). Results show that without raising the stocking density for cattle, there will be no pasture surplus area available for bioenergy. Considering a stocking density of 2.0 animal/ha, pasture surplus area for biofuels varies between 2.6 and 27 Mha, depending on how productive food crops are. If sugarcane is cultivated for AtJ in this surplus area, it can deliver between 260 and 2,676 PJ, meeting at least 49% of projected demand for jet fuel. Considering carbon stocks for planted pasture and sugarcane in the most likely regions to have such expansion, LUC emissions range from -3 to 6 gCO_2/MJ but could be larger in other regions. Producing low carbon AtJ from Brazilian sugarcane to meet the country's jet fuel demand by 2050 is possible but requires coordinated actions to improve both cattle and food systems productivity.

Methods

This study is divided in four sections: (i) land demand by 2050 in Brazil, (ii) pasture surplus area for bioSAF, (iii) potential production of AtJ, and (iv) land use change emissions.

First, pasture and cropland area demanded for food production in 2050 is estimated using Fiorini et al. (2023) data for Brazilian demand of 15 agricultural products, including bovine meat and milk, in conjunction with productivity data from

IBGE (2022) and Angelkorte (2019). Cattle sizes required in 2050 were estimated also using FAOSTAT (2023) and ABIEC (2022) data over meat and milk yield per animal, assuming they remain unchanged in the future. When accounting for beef and dairy herd sizes in 2022, there are 132 million animals not allocated, and so two assumptions were made: this number remains the same in 2050 or it increases in proportion with beef and dairy cattle growth. Four estimates of pasture area for 2050 were obtained combining stocking density values of 2.0 and 1.4 animal/ha with the size of unallocated herds of 132 and 171 million animals.

Secondly, pasture surplus area (A_{sur}) for biofuels production is estimated assuming that intensification of cattle systems will release area for other uses. So A_{sur} was calculated according to Equation 1:

$$A_{sur} = (P_{2022} - P_{2050}) - (C_{2050} - C_{2022}) \tag{1}$$

Where P and C represent the area of pastures and cropland, respectively, and the accompanying number refers to the year. Values for land use in 2022 were obtained from MapBiomas (2023). There are four scenarios for pasture surplus area estimates that combine minimum and maximum crop productivity with minimum and maximum land demanded for pastures.

The third section is the calculation of potencial AtJ production. Data from CORSIA (2022) indicates a yield of 1,313 MJ of AtJ per t of sugarcane. Produtivity for sugarcane in Brazil has an average of 73.6 t/ha (Conab, 2023), and thus using 100% of planted sugarcane to produce AtJ yields 96.6 GJ/ha. Multiplying this value by the size of pasture surplus area results in total AtJ production, which is then compared to Brazil's Jet fuel demand by 2050 considered to be 535 PJ, according to Fiorini et al. (2023).

Finally, direct LUC emissions ($dLUC_e$) are calculated considering that, for Brazil, the difference in carbon stocks of planted pastures (C_{stock_p}) and sugarcane ($C_{stock_{sc}}$) areas ranges from -1.6 to 9.1 tC/ha in a municipal scale (EMBRAPA, 2021). Equation 2 is used to estimate $dLUC_e$ in gCO$_2$/MJ.yr considering 100% is allocated to the bioSAF and an amortization period of 20 years.

$$dLUC_e = \left(C_{stock_p} - C_{stock_{sc}}\right) * 10^6 * 3.667 * \frac{1}{20} * \frac{1}{96{,}600} \tag{2}$$

Results

Cropland in Brazil occupied 61 Mha in 2022, with pastures occupying 164 Mha. Considering the country's projected demand for agricultural products, by 2050 cropland could expand to a total area between 79 and 104 Mha, depending on productivity and assuming double cropping for corn. For pastureland, if stocking density is maintained at current 1.4 animal/ha, the total area ranges from 166 to 193 Mha, meaning there is no surplus pastureland, even for food production expansion. However, when considering 2.0 animals/ha, pastureland might range from 118 to 138 Mha, releasing 26 to 46 Mha. Therefore, pasture surplus area for bioSAF production only occurs when stocking density is higher. This area ranges between 2.6 and 27 Mha. Nevertheless, if unallocated cattle increase to 171 million animals and cropland has minimum productivity, there is no pasture surplus area, even when assuming 2.0 animals/ha.

With 2.6 to 27 Mha available, AtJ production could range from 260 to 2,676 PJ, representing 49% and 500% of projected demand, respectively. Sugarcane AtJ has carbon intensity (CI) of 24.1 gCO$_{2e}$/MJ (ICAO, 2022). With dLUC$_e$ ranging from -3 to 17 gCO$_2$/MJ.yr, the bioSAF's CI could change by -12% to +70%. It is important to note that from the 5570 municipalities assessed, only 106 would have negative dLUC$_e$ and 209 would have maximum dLUC$_e$, with 90% of the cases resulting in values between 1.6 and 15.4 gCO$_2$/MJ.yr. Most of larger emissions occur in the Northeast region where $C_{stocks_{sc}}$ are lower. Considering the most likely states to have available pastureland for sugarcane expansion, (Mato Grosso, Mato Grosso do Sul, Goiás, Minas Gerais and Pará – Bolfe et al., 2024), dLUC$_e$ ranges from -3 to 6 gCO$_2$/MJ.yr.

Conclusions

To be able to release land in Brazil for bioSAF feedstock production, thus avoiding native vegetation suppression, it is crucial to improve productivity in food systems. Most importantly, stocking density rates must rise to alleviate demand for land, but better land use practices, such as double cropping and better agricultural management to optimize yields, are also relevant aspects. Even considering the scenario where livestock occupies the minimum land area, if crop yields are low and, consequently, cropland expansion is high, surplus land for bioSAF will not be enough to meet the projected demand. However, to evaluate if demand could still be met, other alternatives should be analysed. On the higher end, with minimum land for livestock and high food yields, there could be enough surplus land to produce bioSAF that meets five-times that demand.

Regarding dLUC$_e$, they might result in large carbon emissions or even some removals depending on where it occurs. However, considering most likely locations for sugarcane expansion over pastures, dLUC$_e$ affects AtJ carbon intensity in a range of -12% to +25%. It is important to note that this study adopts simplifying assumptions, not addressing subjects such as second-generation biofuels, current bioenergy production, and high uncertainties over carbon stocks estimations, demand projections, systems' productivities, pasture degradation, and others.