



Carbon Balance in the Production of Biomass in Degraded Pasture Areas for the Concession of Incentive to Biofuels in Brazil

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Abstract

Using sugarcane biomass for the production of biofuels is an effective approach to address the issue of climate change. Increasing carbon sequestration in the soil requires changes in land use. The choice of degraded pasture areas located in the state of Mato Grosso, Brazil, for assessing the results of emissions of direct change in land use (d-LUC) was due to the rapid expansion of biorefineries over the last decade. For data collection: i) areas of degraded pasture located in the state of Mato Grosso (MT) were selected to measure the results of d-LUC emissions at various levels of pasture quality; ii) rural properties registered in the Rural Environmental Registry (CAR) that have grown sugarcane in 2020 were considered. According to Guarengi et al. (2023), d-LUC and the effect on the carbon footprint of ethanol were quantified. We adopted these values and calculated the environmental gain for a fuel ethanol enterprise, located in the municipality of Nova Olímpia (MT), whose reduction in the score represents a gain of 19% due solely to the contribution of d-LUC in degraded areas. The resultant reduction in CO₂ emissions boosted the value of decarbonization credits (CBIO), provided by the National Policy on Biofuels, by stimulating demand for cleaner energy solutions. The use of degraded pastureland for biomass cultivation can bring significant mitigation benefits, particularly when combined with Carbon Dioxide Removal (CDR) options and natural revegetation. This highlights that cultivation in degraded areas can not only help mitigate climate change; it can also bring economic benefits to producers, including the increase in the value of CBIO. The purpose of this study is to foster the use of degraded pasture areas to produce biofuels derived from sugarcane in Brazil, while evaluating the economic benefit of strengthening Decarbonization Credits (CBIO), due to the significant mitigation reduction benefits associated with options for Carbon Dioxide Removal (RDC) and natural revegetation.

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Keywords

Biofuels, Bioethanol, Degraded Pasture Areas, GHG reduction, Economic Incentives

1. Introduction

The increasing increase in global biofuel production has been observed since 2000. For instance, ethanol production quadrupled between 2002 and 2020 (OECD/FAO, 2020). Policies to support biofuels in the largest producing regions are motivated by reducing dependence on foreign oil, as they have also sought to mitigate GHG emissions from the consumption of transport fuels and improve rural economic development (Khanna et al., 2021).

There is a consensus that biomass will play a crucial role in the supply of future products currently derived from crude oil. This indicates a shift towards more sustainable energy sources and materials (Jaiswal et al., 2019). However, challenges remain due to the growing demand for food and animal feed, which could intensify competition for land use, along with the impacts of climate change and the need to protect natural ecosystems (Jaiswal, 2017). The following points are particularly important (Gvein et al., 2023):

- (I) Mitigation: Biofuels derived from biomass can reduce carbon footprints compared to fossil fuels, playing a crucial role in climate action.
- (II) Sustainable Land Use: Promoting sustainable land management is essential for preserving biodiversity and ecosystem services.
- (III) Economic Benefits: Expanding biofuel production can create jobs and enhance local farmers' livelihoods, fostering rural development.
- (IV) Regulatory Frameworks and Carbon Markets: Aligning with global initiatives like the Paris Agreement, regulatory measures encourage sustainable practices in the energy sector.
- (V) Scientific Research and Innovation: Research into LUC and carbon sequestration enhances understanding of biomass optimization and ecological trade-offs.
- (VI) Global Food Security: Balancing land use between food and energy production supports food security initiatives.

To contribute to mitigating climate change, the agricultural sector focuses on reducing greenhouse gas (GHG) emissions by implementing practices such as planting biomass on degraded pasturelands. These efforts aim to boost sugarcane-derived biofuel production, adopt land-use change (LUC), and drive habits and customs to enhance soil carbon sequestration. This can help balance the competing demands for land between food and energy production, thereby supporting global food security initiatives (Gvein et al. (2023).

Land-use competition is a determining aspect in assessing the sustainability of biofuels in Brazil (Rutz and Janssen, 2008). Brazil's focus on sugarcane as a biofuel source began in the 1970s, with the introduction of the Proálcool program aimed at reducing dependence on oil imports. Recently, there has been a growing recognition of the potential for using degraded lands for biomass cultivation. The choice of degraded pasture areas in the state of Mato Grosso for biomass production is particularly relevant, as these areas have been identified for their potential to reduce direct land use change (d-LUC) emissions.

According to the OECD/FAO (2020), global projections indicate a 13% growth in ethanol production by the year 2030. Brazil processed approximately 26.78 billion liters of ethanol in the 2020/2021 planting period (CONAB, 2024). The 2018 introduction of the RenovaBio program marked a pivotal step in promoting biofuels in Brazil. This program establishes market mechanisms to recognize the emissions reduction capacity of biofuels, including the certification of production and the issuance of Decarbonization Credits (CBIO). Recent studies have focused on assessing the carbon balance in degraded areas and the impacts of d-LUC over time (Grangeia et al., 2022).

The problem identified in the study is the variability and uncertainty in sustainability impacts, particularly in relation to the GHG reductions from biomass production on degraded lands. The challenges arise from context-specific conditions such as previous land use and biophysical characteristics, which lead to different outcomes in carbon emissions and sequestration. Additionally, there are uncertainties in estimating the scale and impacts of LUC, especially concerning sugarcane plantations, and the need for tailored, location-specific approaches to effectively manage these challenges. These issues complicate the broader application of findings across regions, making it difficult to generalize results and optimize biomass production strategies for GHG reduction. Neglecting the cultivation of biomass in degraded areas without proper management can increase GHG emissions and prevent the realization of carbon sequestration benefits. This could perpetuate dependence on fossil fuels and contribute to rising carbon footprints.

Ethanol production using low-productivity pastures to grow sugarcane is a sustainable way to expand the sugarcane cultivation area and, therefore, increase the production of bioenergy (Cherubin et al., 2021). Possible alternatives for enhancing carbon sequestration from the atmosphere encompass: expanding the production of bioproducts through industrial means, capturing carbon in sugarcane plantations, promoting the use of biofuels, advancing technological and industrial processes for negative emissions, and recycling agricultural waste (Cerri, 2022).

The implementation of LUC can yield immediate benefits and long-term improvements in soil health and carbon sequestration (Mello et al. 2014 apud Cerri, 2022).

On a global scale, unresolved issues in biomass production can affect Brazil's role in global climate change mitigation efforts. As a significant player in the biofuel market, Brazil's failure to optimize biomass production could undermine international commitments to reduce greenhouse gas emissions and achieve sustainability goals. Several studies have contributed to the understanding and greater acceptance of the environmental impacts of biomass production, not only in terms of land use change and carbon sequestration but also particularly in the context of Brazilian agricultural practices (Novaes et al., 2017; Donke et al., 2020; Gvein et al., 2023; He et al., 2024).

There is a growing consensus on the importance of using degraded lands for biomass production. Studies indicate that shifting arable land to the cultivation of perennial energy crops can increase water use efficiency and significantly reduce GHG emissions. Although biomass production for biofuels offers promising opportunities, if not managed carefully, it can also pose significant risks. LUC represents a large contribution to global CO₂ emissions (IPCC, 2014 apud Novaes, et al., 2017). Predicting the scale and impacts of sugarcane plantations is fundamental, especially in Brazilian states with extensive agricultural areas and varied emission profiles. States in the southern and central-western regions generally have low associated emissions, while those within the Amazon biome have the highest CO₂ emission rates, mainly due to the expansion of grain plantations (Novaes et al., 2017).

The analysis considered geographically detailed land conversion data and comprised the assessment of emissions resulting from d-LUC, as described by Novaes et al (2017). The data was updated based on research conducted by Donke et al. (2020) taking into consideration the impact of d-LUC over 20 years. This resulted in the creation of datasets (life cycle inventories) that provide regionalized information on d-LUC in Brazil. Improvements include regionalized carbon stocks and d-LUC categories for pastures and forests.

Sustainable farming practices can be optimized by repurposing abandoned cultivated land and marginal lands. By integrating abandoned agricultural land and measuring specific biomass yields, these approaches can achieve optimal mitigation potential. According to Gvein et al. (2023), utilizing land and prioritizing natural revegetation in areas of high biodiversity importance and remaining lands can lead to substantial improvements in greenhouse gas balance when evaluating options for CDR.

However, one of the critical limitations highlighted in the literature is the dependency of sustainability impacts on context-specific conditions, such as previous land use and biophysical characteristics. This variability can lead to trade-offs between GHG decreases and other sustainability purposes, making it essential to tailor approaches to local conditions. Other results highlight the potential of marginal lands and specific perennial crops to contribute to biomass production and CO₂ reduction. At the same time, they emphasize the need for further research and economic analysis to facilitate this transition (He, Y. et al., 2024).

The knowledge gap in this text lies in the uncertainty and variability surrounding the sustainability impacts of LUC, particularly regarding the estimation of GHG emissions and carbon sequestration. While methods like BRLUC 2.0 offer a framework for estimating LUC scenarios and emissions, they do not fully address the potential uncertainties or the complete impacts on emissions, especially across different regions. Furthermore, there is a need for more refined assessments when related to d-LUC and CO₂ emissions that are correlated with the stage of sugarcane cultivation, thus covering the role of planting driving habits and customs and the management of changes that have occurred in carbon stocks over time. More research is required to understand how varying conditions, such as previous land use and biophysical characteristics, influence GHG reduction outcomes and to improve the applicability of findings across diverse regions. A major limitation is the variability in sustainability impacts based on context-specific

conditions, such as previous land use and biophysical characteristics. This inconsistency can lead to different outcomes in GHG reductions, making it challenging to generalize findings across different regions.

There is significant controversy surrounding the most suitable methods for estimating LUC and its associated emissions. The presence of indigenous carbon reserves and the time of planting due to agricultural expansion are decisive factors in the pattern of GHG emissions. The BRLUC 2.0 method, developed for Brazil, estimates 20-year LUC scenarios and CO₂ emission rates with grains, pastures and native forests in the country in each of the 27 states. To provide a framework for estimating LUC scenarios, the magnitude of uncertainty and its potential impact on total emissions remain inadequately addressed. It is based on temporal statistics and is in line with the most widely used standards to determine carbon footprints.

This approach can contribute positively to net carbon removal in the Brazilian agricultural sector, influencing both bioenergy and agricultural sustainability. In addition to reducing CO₂ emissions, biomass cultivation in degraded pasture areas can boost the recovery of such areas and promote environmental sustainability.

Research on the calculation of emissions caused by d-LUC associated with sugarcane cultivation has shown the importance of considering the effects of d-LUC associated with agriculture. This refined assessment of LUC and CO₂ emissions directly linked to the sugarcane planting phase includes the adoption of changes in appropriate driving habits and customs and soil carbon stocks over the last twenty years. (Guarenghi et al., 2023). To mitigate climate change, reducing GHG emissions in the agricultural sector includes planting biomass in degraded pasture areas, thereby increasing the production of sugarcane-derived biofuels, as well as LUC practices and driving habits and customs to increase carbon sequestration in the soil.

The goal of this study is to evaluate the use of regions with degraded pastures in Brazil to produce ethanol derived from sugarcane, while simultaneously evaluating the associated environmental and economic benefits. Specifically, the study focuses on assessing the economic advantages of CBIO as a tool for promoting CDR and natural revegetation, which contribute to climate change mitigation. Encourage the adoption of sustainable agricultural practices that align with environmental criteria for biomass cultivation, aiming to revitalize degraded areas while reducing greenhouse gas emissions.

The models adopted provide a variation in CO₂ emission rates from LUC according to different possibilities of land use transition, which can contribute with a great impact on the results (Novaes et al., 2017). The effort to avoid GHG emissions per hectare is greater thanks to the possibility of producing more biomass by adopting a new unused area, favoring the non-use of fossil fuels. The use of degraded pasture areas influences the carbon balance and can represent a significant advantage in LUC emissions. (2023) consider that increasing pastures for biofuels is an option that can be adopted to expand the areas necessary for sugarcane production, preventing an additional influence on the displacement of food crops or livestock. Sugarcane ethanol produced in integrated pasture scenarios has outperformed conventional systems. In this context, the National Biofuels Policy (Renovabio) is based on incentives to promote the valorization of Decarbonization Credits (CBIO) granted to biofuel producers according to the higher Environmental Energy Efficiency Scores (NEEA).

Decreased GHG emissions during the sugarcane planting phase favor the assessment of this stage and improve the NEEA. Therefore, there is a greater reduction in GHG for the equivalent quantity of ethanol produced. CBIOS to promote the valorization of degraded pasture areas instead of converting them into areas for cultivating perennial cereals can lead to significant environmental benefits.

The state of Mato Grosso was chosen for this study due to its rapid growth of biorefineries, which process both sugarcane and corn, as noted by Moreira et al. (2020). We explore the potential of using degraded pasturelands in Brazil for biofuel production, particularly focusing on sugarcane. The datasets allow LUC to be incorporated into Brazilian agricultural products, at state, regional and national levels, showing a reduction in GHG emissions for soybeans and sugarcane. Donke et al. (2020) identified improvements that had a significant impact. These include: (i) modeling LUC at the state level with official national data; (ii) regionalized carbon stock; (iii) inclusion of pasture and forest LUC categories; and (iv) considering sugarcane as a perennial crop. Minor changes in data sources and assumptions significantly impact emissions directly linked with LUCs in agricultural products. Furthermore, it also demonstrated the substantial impacts of the imprecisions associated with the LUC standard.

This study, based on the calculation of emissions caused by d-LUC associated with sugarcane cultivation, has shown the importance of considering the effects of d-LUC associated with agriculture and identifying and recommending driving habits and customs that can optimize biomass production while ensuring long-term sustainability and environmental benefits, addressing the gaps in current literature regarding effective strategies. This refined assessment of LUC and CO₂ emissions directly linked to the sugarcane planting phase includes changes in appropriate activities and land carbon stocks over the last twenty years (Guarengi, et al., 2023).

2. Method

2.1. Selection of producers and areas

The process of selecting the areas under study involves identifying rural properties with rural environmental registration (CAR) that were engaged in sugarcane cultivation in 2020, in the state of Mato Grosso (MT). The National Petroleum Agency's (ANP) Dynamic Panel, ANP (2022) enables the identification of cities and producers who are compliant with CAR and approved to take part in Renovabio.

The steps are: (I) Identification of the biofuel producer and the location of the municipality that produced sugarcane in 2020 based on the selection of producers in MT. (II) Assessment of Pasture Quality in these mapped areas, with the identification of available pasture areas, and quantification of pasture area to meet the projected annual increase for each producer; and (III) Potential Gain from Valorization of CBIO, indicating the projected environmental gain based on the estimated NEEA of each producer.

Based on the eligible volume of each certified producer, an estimate of the area required to meet the expected growth demand by 2030:

$$\text{Quantification of Additional Area (ha)} = \frac{\text{Quantity Sugar Cane Harvested (tonnes)} \times \text{Annual Growth of 1,29 \%}}{\text{Average Productivity (tonnes/ ha)}} \quad (\text{eq 1})$$

Contribution of d-LUC alone in degraded areas based on the net carbon emission/removal:

$$\text{Contribution of d - LUC (\%)} = 1 - \frac{(\text{NEEA Score } (\frac{\text{gCO}_2\text{eq}}{\text{MJ}}) - 11.21 \text{ Quantified d-LUC } (\frac{\text{gCO}_2\text{eq}}{\text{MJ}}))}{\text{NEEA Score } (\frac{\text{gCO}_2\text{eq}}{\text{MJ}})} \quad (\text{eq 2})$$

d-LUC (%) = Contribution of the d-LUC effect to the NEEA score.

NEEA Score = Net Ecosystem Exchange of Carbon Dioxide (NEEA) refers to the balance of carbon dioxide (CO₂) emissions and uptake within an ecosystem.

-11.21 gCO₂eq/MJ = d-LUC effect on ethanol's carbon footprint indicates withdrawal based on net carbon emission/removal correlated with sugarcane planting areas.

The option to use the Dynamic Panel, depicted in Figure 1, allows us to obtain certified producers with their respective CARs.

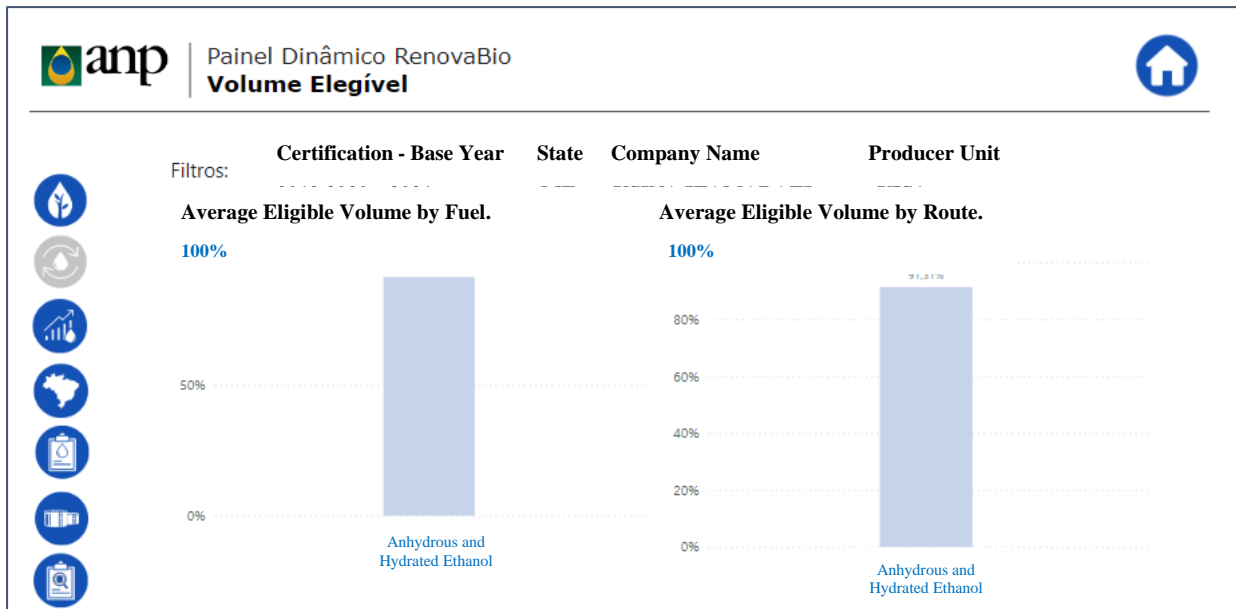


Figure 1: Dynamic Panel of ANP –ITAMARATI – MT (Source: Dynamic Panel of ANP, 2024)

Figure 2 shows the detailed flowchart of the adopted methodology, and the next subsections explain the different steps of the methodology. Regarding Renovabio, the question of LUC is linked to the choices of the means by which the raw materials for biofuel production are sourced. Biomass cannot be sourced from areas where native vegetation covering was suppressed after November 2018 and cannot have a suspended CAR.

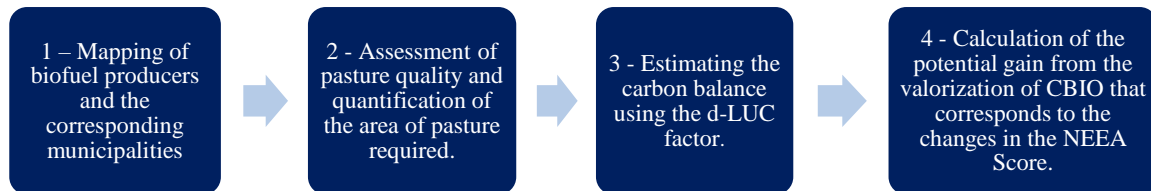


Figure 2: Methodological approach

The CAR (Rural Environmental Registry) is a georeferenced document that shows the limits of each private property in Brazil. It is the authorized instrument for compliance with environmental laws on agricultural properties in accordance with the Forest Code, as highlighted by Sparovek, et al. (2019). The Forest Code is the main regulation for the protection of areas of native and natural vegetation in Brazil, establishing standards for the protection of permanent protection areas and maintenance of the Brazilian Native Legal Reserve (2012) - Forest Code. Monitoring is conducted by means of the Rural Environmental Registry, which indicates what actions are required to comply with the legislation indicated in the Environmental Recovery Program.

The choice of areas followed the recommendation of Guarenghi et al. (2023), considering properties that grow sugarcane and have CAR. This condition ensures that these producers comply with the Forest Code in relation to permanent protection areas and eliminates the adoption of recently deforested areas, as required by the National Petroleum Agency (ANP).

The spatial distribution of CAR was obtained from IMAFLORA Atlas da Agropecuaria Brasileira (2022). Properties with the most recent approval data (registrations from 2020 onwards) were considered, according to SICAR (National Rural Environmental Registry System). The CAR database was integrated with information on sugarcane cultivation areas from 2020, obtained from MapBiomass. (2021).

The survey on data about the extent of degraded pasture areas from MapBiomass (2021) was used to assess the level of quality of pastures in each region and in each year, according to Pereira et al. (2016) and Santos et al. (2022), with the geographical location of areas suitable for growing biomass for biofuels, considering the factors of water availability, type of soil and potential for production of biomass.

Regarding the mapping of degraded areas, the data was collected from the Pasture Atlas developed by the Image Processing and Geoprocessing Laboratory of the Federal University of Goiás (Lapig/UFG), available at the UFG (ATLAS DE PASTAGENS, 2024).

Audit Validation Reports obtained from the Certifiers at Greendomus (2024), data was collected on yield per eligible area, yield per refinery, city, and year of production.

2.2. Measurement

According to Gurenghi, et al. (2023), the data on carbon stocks were used from the BRLUC method as a reference. The summary of the carbon stocks for the categories of land use, according to Garofalo et al. (2022), are included in the BRLUC method and adopt the IPCC as sources for factors of management, input and land use. In the case of carbon stocks in grain biomass, it adopts factors from the European Commission and in the case of carbon stocks in pastures, it adopts factors from the Third National Communication (2016). The data can be improved by adopting driving habits and customs and including carbon stock values (Tier 2) to obtain more accurate results for d-LUC emissions for different pasture quality levels. In relation to biofuel products and products derived from the border areas defined by the CAR, they can serve as a differentiating factor and a tool to monitor d-LUC correlated to the planting series, the cultivation system and related habits and customs the preservation of natural vegetation or compliance with local regulations (Guarenghi, et al., 2023). This study used moderate degradation of pasture, which is the prevailing condition in Brazil (Dias-Filho, 2014 apud Guarenghi et al., 2023); Ferreira et al., 2014 apud Guarenghi et al., 2023). The study took average values from the Intergovernmental Panel on Climate Change (IPCC) for crop management. We also consider parameterization data, such as pasture quality levels, automated harvesting history, determination of the carbon stock of sugarcane biomass and adherence of the carbon stock of crop biomass to the IPCC (annual mode).

Guarenghi et al. (2023) quantified d-LUC and the emissions associated with sugarcane crops, including changes in driving habits and customs and carbon stock factors associated with d-LUC. The data was adjusted for the last two decades in Brazil in the center-west and southeast regions. Carbon data from the BRLUC V.2 method, according to Garofalo et al. (2022), which provides soil carbon stock data, was used as a reference.

3. Results

More specifically, it considers the economic advantages of increasing Decarbonization Credits (CBIOs) by measuring the positive balance of greenhouse gas emissions associated with carbon dioxide removal (CDR) and natural revegetation options.

The carbon balance in degraded areas can represent a significant advantage, acting as a tool for monitoring d-LUC emissions in relation to products, cultivation systems and natural vegetation preservation practices (Guarenghi et al., 2023). Studies indicate the need to conduct a comprehensive assessment of raw materials and biomass supply chains. The history of land use and raw material sourcing is more relevant than other specific conditions.

The transition from cultivating arable land to growing perennial energy crops leads to enhanced synergy, particularly regarding water use efficiency (Vera et al., 2022). There is a consensus on prioritizing the reduction of greenhouse gas emissions and revitalization of rural areas, particularly in the comprehensive evaluation of biomass raw materials (Mola-Yudego et al., 2024), confirming the significant potential for improvement for the entire agricultural system through LUC studies for biofuels highlight. According to Macedo, I.C. et al (2015), under the right conditions, biofuels have the potential to significantly reduce the levels of GHG.

The method adopted enables Life Cycle Analysis (LCA) and Carbon Footprint (CFP) practitioners to easily incorporate d-LUC emissions for agricultural products at a regional, state and national level. According to Donke, A.C.G. et al., the year 2020 provides a more comprehensive representation of the diverse biome patterns in various parts of Brazil, while also recognizing sugarcane as a permanent crop.

3.1. Identification of cities that produced sugarcane in 2020

In the example, we have ITAMARATI, in the city of Nova Olimpia - MT. In the same spreadsheet, we identify producers by state and the respective biofuel data: eligible volume, year, city, energy efficiency score (NEEA), and emission factor. Table 1 indicates producers of sugarcane-derived biofuels and the respective production parameters.

Table 1: List of sugar cane producers in the state of Mato Grosso (year 2020). (Source: Adapted by the authors)

List of sugar cane producers by state				Renovacalca			Certif		
State	Municipality	Producer	Biofuel	Area planted (ha)	Sugar Cane Haverst (ton)	Mill income (ton/ha)	NEEA (gCO ₂ eq/MJ)	Emission Factor (ton CO ₂ eq/litro)	Eligible Volume (%)
MT	Nova Olimpia	ITAMARATI	Etanol Anidro-E1GFLEX	224840,56	14864687,11	66,11	58,21	1,881E-03	91,31
MT	Nova Olimpia	ITAMARATI	Etanol Hidratado-E1GFLEX	224840,56	14864687,11	66,11	57,86	1,881E-03	91,31
MT	Sorriso	BURITI	Etanol Hidratado-E1GC	2363,00	126672,90	53,61	28,74	6,133E-04	100,00

3.2. Quality of pastures per city

In 2020, the center-west region, where the state of Mato Grosso is located, accounted for 27% of the sugarcane area in Brazil (Guarenghi et al., 2023). Similarly, with the expansion of sugarcane, there has been a reduction in the area of pasture and temporary crops in the total area of rural properties that grow sugarcane. An example is the city of Nova Olímpia (MT), Figure 3, which is characterized by having approximately 50.6% of pastures in a severely degraded condition and approximately 46.4% of pastures in an intermediate condition.

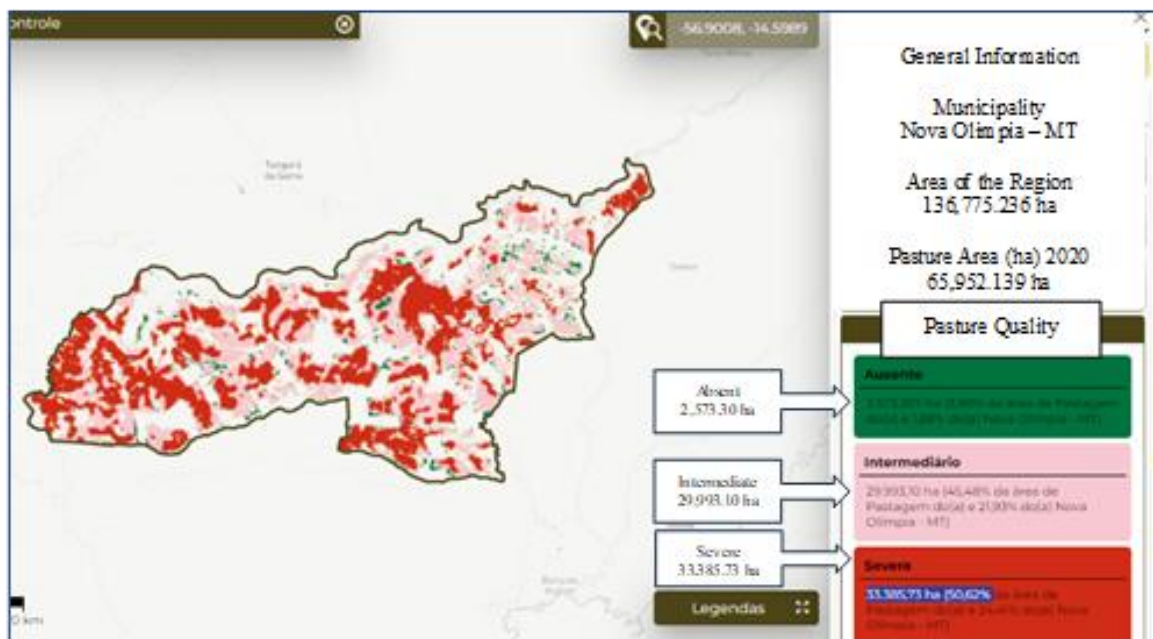


Figure 3: Map of pastures in the city of Nova Olímpia (2020) (Source: Pasture Atlas, 2024)

3.3. Potential Increase in CBIO Value

Data from the state of MT showed a reduction in GHG emissions when compared to gasoline, and considerable socio-economic benefits at national and local levels in a positive carbon balance, resulting in environmental gains when considering LUC emissions, producing biofuel with greater efficiency in the GHG balance. Based on the eligible volume of each certified producer, an estimate of the area required to meet the expected growth demand by 2030 is obtained, indicating a 13% increase in the production of ethanol by the year 2030 (OECD/FAO, 2021), which results in an annual growth of 1.29%.

Considering the harvest data in the follow-up reports on the Brazilian sugarcane harvest published by CONAB (National Supply Company), we have ethanol production data published annually: area under production, productivity, production and quantity of sugarcane to produce sugar and ethanol. Table 2 is a summary of the producers' data.

Table 2: Data of harvest of producer – 2020/21 harvest (Source: CONAB, 2022)

Producer	Planted Area (ha)	Quantity of Sugar Cane Harvested (tonnes)	Average Productivity (kg/ ha)	NEEA (g CO ₂ eq/MJ)
ITAMARATI	224840,56	14864687,11	66110	58,21ha

To calculate the area needed for each biorefinery, we have to consider the amount of cane processed.

Table 3 is a summary of scaling area expansion data.

Table 3: Scaling the area for expansion. (Source: Elaboration of the authors)

Rate (%)	Area Additional (ha)	Quantity Sugar Cane Additional (tonnes)
1,29	2900	191748

Considering the data of the producer's (ITAMARATI) harvested sugarcane and mean productivity (20/21 harvest), we obtained the area needed for planting: the area needed for planting was 224840.56ha. And considering the 1.29% increase, it results in an additional area of 2,900 ha. The city of Nova Olímpia (MT) has sufficient moderately degraded pasture area (29993 ha), as shown in Figure 2.

According to Guarenghi et al. (2023), the average data indicated that the consequence caused by d-LUC on the carbon footprint of ethanol reproduces the removal of -11.21 gCO₂eq/MJ based on the net carbon emission/removal associated with sugarcane areas. Sugar in RCAs, during 2000-2020.

For the example given, the ITAMARATI producer received an NEEA Score = 58.21, considering the contribution of d-LUC = -11.21, we got an NEEA Score (d-LUC) = 47.00. This reduction in score represents a gain of 19% due to the contribution of d-LUC alone in degraded areas.

The gains obtained from the reduction of GHG emissions increase the efficiency of biofuel production plants and indirectly increase the evaluation of NEEA, resulting in a potential gain of CBIO, used in the biofuels market regulated by Renovabio.

4. Discussion

The results obtained for the state of Mato Grosso with the use of degraded pasture areas to plant biomass for biofuels and the reduction of carbon in the soil resulted in environmental gains when considering LUC emissions, resulting in biofuel with greater efficiency in the GHG balance.

Regarding this specific case, ITAMARATI was able to reduce emissions from direct Land Use Change (d-LUC) by adopting degraded areas assuming an average gain of 19%. The positive results are associated with the d-LUC effect on the ethanol carbon footprint. As well as obtaining more sustainable biofuel and reducing GHG emissions, biomass cultivation in degraded areas allows for the recovery of pasture areas, increases carbon fixation in the soil and favors revegetation.

Despite the robustness of the approach as demonstrated by the BRLUC 2.0 method, which is in alignment with other methods at the global level (Blonck Consultants, 2016, BSI, 2012), it is necessary to consider the uncertainty aspect, its magnitude and the potential impact on total emissions of agricultural products.

The impact of land use for specific agricultural production can result in trade-offs between GHG emission reductions depending on specific context conditions. Some authors, Donke et al. (2020), and Moreira et al., (2020), reinforce that sustainability impacts and, therefore, sustainability trade-offs of biomass planting are largely context-dependent (e.g., previous land use, type of raw material, biophysical conditions).

According to Gvein et al, (2023), this cultivation option using degraded areas can achieve optimal mitigation potentials, however, it is very important to consider other regions and increase the number of measurements to reduce potential deviations in the results. Thinking of a global implication, mitigation using degraded or abandoned land can help minimize the risks associated with competition for land. However, the highest biomass yields are found in the tropical band, which is crucial for maximizing energy production.

The practices that increase carbon sequestration from the atmosphere can make a positive contribution to net carbon removal in the biofuels sector, according to Cerri et al., (2022).

According to Grangeia et al (2022), the RenovaBio program was developed with the objective of incorporating market instruments to admit the capacity of each biofuel to reduce emissions: in the fuel matrix, this was designated national reduction parameters (defined for a period of 10 years) and certification of biofuel production, assigning different grades to each producer (higher grades will be given to the producer that produces a greater amount of net energy, with lower CO₂ emissions, in the life cycle).

The creation of CBIO, one of the instruments created, links these instruments. CBIO is an asset traded on the stock exchange, issued by the biofuel producer. With the creation of the regulated carbon market, questions arise about the CBIO trading market. The biggest of these is the definition of how the mechanisms for regulated carbon markets would be applied as proposed in Article 6 of the Paris Agreement (Grangeia et al, 2022).

Also, it is necessary to solve governance and institutional arrangement impasses to develop the framework to promote mitigation, projects and actions, on the necessary scale in Brazil.

5. Conclusion

The reduction of GHGs favors the valorization of CBIO by increasing the demand for renewable energy solutions with greater GHG reductions. As biorefineries produce biofuel with greater GHG balance efficiency, the value of certificates associated with carbon reduction increases. CBIOs can be utilized by producers with GHG reduction targets to mitigate their own emissions or to offer them to third parties in order to enhance their value. In comparison to gasoline, these practical strategies demonstrated substantial reductions in greenhouse gas emissions when assessed under the current representative conditions of the state of Mato Grosso, Brazil.

Importance of considering context-specific conditions in evaluating synergies and trade-offs and their relevance for sustainably developing appropriate policies and practices.

Options using degraded areas are crucial complements to the reduction of fossil fuel emissions, whose action can help phase out fossil fuels. The adoption of more sustainable practices with the adoption of environmental criteria for biomass cultivation can promote planting in degraded areas, favoring the valorization of CBIO and also boosting the recovery of these areas. And thus, encourage other farmers to produce bioethanol by adopting the same practices.

Notwithstanding, RenovaBio has increased the biofuels market, reducing fossil fuel emissions in the transport sector, in addition to being the first carbon pricing approach implemented in Brazil, these issues highlight the need for a deep understanding of the Program, as well as variants that directly correlate with this policy.

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Ethics Approval

Not applicable.

Conflict of interest

The authors declare there is no conflict.

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