Land use change: the barrier for sugarcane sustainability

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Abstract

Bioethanol production in Brazil gained momentum in the 1970s and 1980s as an energy security and energy sufficiency measure due to the well-known world oil crisis. However, the increase in bioethanol production and consumption in the past couple of decades has been backed by the country's efforts to reduce greenhouse gas (GHG) emissions in the transport sector. Brazil is the second-largest producer of biofuels, and its production continues to increase because of the commitments made to the Paris Agreement in 2015. This study reviews several key policies designed to develop Brazilian bioethanol production and to protect the environment. It is argued that many of these policies do not consider land use change nor encourage land protection to achieve sustainable land use and agricultural production. Thus, this work aims to understand the importance and impacts of public policies in expanding sugarcane in Brazil in the past 34 years regarding land use and native vegetation. The discussion in this paper addresses the inadequacy of current policies to avoid the direct and indirect conversion of natural vegetation areas to sugarcane, despite incentives such as 17 Sustainable Development Goals from the United Nations and certification schemes. Data presented indicate an indirect effect caused by the expansion of sugarcane over pasture areas, which leads to further clearing of natural vegetation to establish new pasture areas. Ultimately, this study addresses the importance of zero deforestation in Brazil, regardless of the crop that causes the conversion. Without conjoint efforts by all sectors of the economy to curtail deforestation, the sustainability of producing biofuels is not guaranteed, as the emissions caused by deforestation will not be offset by the lower GHG emissions obtained by using ethanol as a transport fuel.

Keywords— Biofuels; land policies; indirect land use change; good practices

1 Introduction

Over the past few years, the scientific community has increasingly focused on bioenergy production, including biofuels, and their effects on food production and the energy-food nexus [1, 2, 3, 4]. The interest in biofuels in industrialized countries lies in their potential to reduce GHG emissions in the transport sector [5, 6]. Some studies have shown that the expansion of biofuels has caused indirect impacts on the environment [7, 8, 9], particularly on the net benefits of GHG emissions after conversion of native vegetation are taken into account, on food production, water, and biodiversity [6].

Brazil had approximately 10.11 Mha of sugarcane in 2019 to produce bioethanol, sugar, electricity, and steam for process in combined heat and power plants (CHP) [10]. Sugarcane production in Brazil has increased over the last 20 years, driven by flex-fuel vehicles' production and the growing demand for sugar exports [11] (Figure 1). According to the OECD-FAO Agricultural Panorama 2019-2028 [12], Brazil will continue to be the primary sugar and sugarcane-based ethanol producer in the coming decade. In the period up to 2028, Brazil is expected to produce 37% of global sugarcane, which will contribute to 18% of global sugar production, and 88% of global production of sugarcane-based ethanol [12]. Ethanol is the cornerstone for Brazil to fulfill its commitment described in its Nationally Determined Contribution (NDC), presented at COP21 in 2015 [13]. The Brazilian

NDC predicts a 37% reduction based on 2005 levels in greenhouse gas (GHG) emissions by 2025 and 43% by 2030. To this end, the share of the energy matrix attributed to biofuels is expected to reach 18% by 2030, requiring a 25 billion liters increase in bioethanol production (from 29 billion in 2014 to 54 billion in 2030) [14].

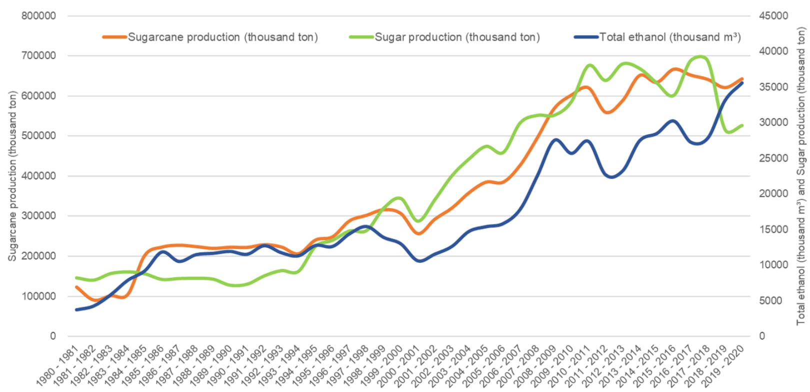

Figure 1: Sugarcane production (thousand ton), Sugar production (thousand ton), and Total ethanol (thousand m^3) in Brazil, from 1980 to 2020. Source: [15]

To align the expansion of biofuel-producing crops and agriculture with protecting natural areas and reducing GHG emissions, Brazil has established a set of public and private land use policies and control mechanisms [16]. Among the most significant policies and commitments established in Brazil is the Low Carbon Agricultural Plan (ABC Plan, Law 12.167/2009), the new Forest Code, including the Rural Environmental Registry (CAR) and the Environmental Regularization Program (PRA) (Law 12.651/2012). The sugarcane agroecological zoning (SAZ) (Decree 6.961/2009), that established in which regions of Brazil sugarcane could expand with public rural credit, was recently revoked (Decree 10.084/2019). In 2017, the Brazilian Government launched the National Biofuels Policy (RenovaBio) (Law 13.576/2017), intending to expand the production of biofuels in Brazil and reduce GHG emissions. This policy will encourage the expansion of sugarcane to produce ethanol, motivated in part to combat a ten-year drop in global sugar prices [12].

However, it is known that competing land uses continue to promote rapid changes in land cover, which affects ecosystem services

[17]. With the recent changes in Brazilian positioning towards environment protection, it is more important than ever to learn from past experiences to understand what policies need to be in place to increase agricultural and biofuels production without further loss of native vegetation and striking environmental impacts such as increased GHG emissions. Thus, this work aims to understand the importance and impacts of public policies in expanding sugarcane in Brazil in the past 34 years regarding land use and native vegetation. This analysis discusses the effectiveness of these public policies and will serve as the basis for establishing future directions in environmental protection related to the promotion of biofuels and agricultural production.

In section 2, we present six important public policies introduced in the past 46 years to develop the sugarcane industry and reduce GHG emissions in the forest and agricultural sectors. Section 3 presents the trajectory of land conversion in Brazil. Section 4 looks at the sustainable development goals, section 5 discusses sugarcane certification, land use and land cover. In section 6, we propose future directions for sustainable sugarcane production, and in section 7, we present our conclusions.

2 Public policies for sugarcane and agriculture and their relationship with land use

This section describes the country's policies over the past 46 years that have affected the expansion of sugarcane or that have served to, directly or indirectly, manage the GHG emissions of agriculture and sugarcane production.

2.1 Proalcool

In Brazil, until the end of the 70s, sugarcane monoculture was not significant and highly concentrated in the São Paulo State. In 1974, Brazil harvested $\approx$ 2 Mha while the state of São Paulo harvested $\approx$ 0.7 Mha, jumping to $\approx$ 10.1 Mha in Brazil and $\approx$ 5 Mha in the state of São Paulo in 2019 [10]. The contribution of sugarcane to the agricultural economy in the beginning of the 1970s was proportionally greater than the area it occupied. This occurred because it produced relatively high valued agribusiness products (sugar and sugarcane liquor – *cachaça*), which had more stable prices and consumption markets.

With the fall in sugar prices in 1974 and following the oil crisis at the beginning of the decade, the sugarcane sector and the Brazilian Government saw an opportunity to supply energy using national resources. Additionally, ethanol production would help to diminish the idle crushing capacity in sugar mills inherited from the first half of the 1970s, which resulted from an overestimated projection of sugar exports expansion [18, 19]. In 1975, the Proalcool program was established by a decree [20] and aimed mainly at reducing oil imports, which made up 47% of Brazilian imports at the time [19]. The program contemplated the construction of new ethanol plants with low-interest loans and established a mandatory mixture of ethanol and gasoline to meet the domestic markets needs [21]. Later, in 1979 by another decree, the Brazilian Government reinforced the program through tax cuts for fuel and vehicles running on ethanol [22], boosting the sales of new vehicles powered completely by hydrated ethanol [21].

In the 1980s, legislation authorized private financial companies to grant credit lines to Proalcool participants. The Government also favored the expansion and consolidation of ethanol through tax incentives (reductions) directed to the ethanol-producing sector. Taxes on ethanol vehicles were about 5% lower than gasoline vehicles, and ethanol was tax-free for final consumers. The sector received the program well and saw great potential in the bank credits and subsidized interest offered by the government [23]. For more information on the Proalcool program, see Moreira et al. [24].

Even though today ethanol is considered an essential tool for fighting climate change, back then, the interest in this fuel was merely related to energy security or, more accurately, energy sufficiency [25]. The law that established the Proalcool program made no mention of "environment", "climate," "deforestation," or even "land" [20]. Most of the issues related to land use dealt with in the local literature at the time were centered on land grabbing, the concentration of land ownership, the vertical integration of agriculture, and the expansion of sugarcane over other crops and native vegetation [26, 23, 18, 19, 27, 28].

With an increase of 62% in the cultivated area in only five years (1975-1980), São Paulo State, which benefited most from Proalcool investments, saw a diversion of land to supply cane to new distilleries, and an increase in the concentration of sugarcane production, with a decrease of the share of sugarcane supplied by outgrowers from 75%

to 28% in the 1975-1980 period [18]. The average area of the agricultural establishments in this State has been progressively increasing, while agricultural establishments with an average area of fewer than 10 hectares have decreased [23].

Sugarcane expansion during the Proalcool era took place mainly over pasture areas, other agricultural areas, forests, reforestation, and native vegetation [26]. In São Paulo State from 1975 to 1984, the area of sugarcane went from 15.7% of the total planted area to 28%. In absolute terms, sugarcane, soybean, coffee, and orange production expanded to the detriment of rice, potatoes, cassava, and other food crops [28]. Veiga Filho et al. [29] explain that from the harvest season of 1978/79 to 1988/89, sugarcane expanded 884,700 ha, followed by orange (342,300 ha), corn (109,400 ha), and soybeans (18,800 hectares). They show that these expansionary activities in that period replaced 518,500 hectares of land occupied by other crops, as well as 341,800 ha of pasture, 272,900 ha of reforested areas, and 223,200 ha of forest and natural vegetation. Other states also felt the expansion of sugarcane at the time Proalcool was in place. In Southeast of Goiás (Center-west of Brazil), for example, the expansion of sugarcane in the 1985-1995 period occurred primarily over agricultural areas (16,953 ha), followed by the replacement of areas of natural vegetation (5,559 ha) [30].

2.2 Sectoral plan for mitigation and adaptation to climate change for the consolidation of a low carbon economy in agriculture (ABC Plan)

The sectoral plan for mitigation and adaptation to climate change for the consolidation of a low carbon economy in agriculture (ABC Plan) is a national instrument for integrating the actions of the Brazilian Government, the productive sector, and civil society to reduce GHG emissions from agricultural and livestock activities (article 3 of Decree 7.390/2010), which was in force from 2010 to 2020. The ABC Plan comprised seven programs that involved the recovery of degraded pastures; crop-livestock-forest integration and agroforestry systems; no-till farming systems; biological nitrogen fixation; planted forests; animal waste treatment; and adaptation to climate change.

The ABC Plan provided a rural credit line that aimed to finance the implementation of low carbon agricultural practices or technologies that contribute to climate change mitigation and adaptation. The plan's original investment was budgeted to be approximately $R\$197$ billion (Brazilian currency).

However, available data show that investments reached $R\$17.3$ billion in 2019 [31], with an additional $R\$1.9$ billion in 2020 [32]. Gianetti et al. [33] mention shortcomings in carrying out the program in the North and Northeast regions on a large scale, highlighting the importance of promoting Technical Assistance and Rural Extension (ATER) actions. According to the authors, it is also necessary to implement tools to monitor GHG mitigations and interest rate adjustments to make the program more attractive than other rural credit options. Even though the ABC plan's total investments reached approximately 10% of the planned amount, the Government has published optimistic data on its success. The Brazilian Ministry of Agriculture, Livestock and Food Supply (MAPA) reports that all the plan's major goals had been achieved already in 2016 [34]. However, the goal related to the recuperation of degraded pastures was not accomplished by the plan, with only 30% of the target area achieved in 2018. Although it is practically impossible to verify the results shown by MAPA [34], the agricultural sector GHG emissions have remained steady in the past ten years at around 480 million tons of CO_{2e} per year [35], while production is growing. When it comes to sugarcane, since the plan was not focused on one particular crop, producers would have benefited from the Plan through its Biological Nitrogen Fixation (BNF) actions, as mentioned in [36]. However, the credit directed towards BNF corresponded to less than 1% of total investments, according to Gianetti et al. [33].

2.3 Sugarcane agroecological zoning (SAZ)

Decree 6.961, from July 26, 2009, approved the sugarcane agroecological zoning (SAZ) and ordered the National Monetary Council (NMC) to establish rules for financing operations in the sugar and alcohol sector, under the terms of zoning. SAZ evaluated the potential of land for sugarcane cropping (without irrigation) for ethanol and sugar production as a basis for planning sustainable land use.

SAZ was based on a study carried out by the Brazilian Agricultural Research Company (Embrapa). This study shows the location of areas suitable for sugarcane expansion following these guidelines [37]:

- Exclusion of areas with original vegetation, and an indication of areas currently under anthropic use;

- Exclusion of areas for cultivation in the Amazon and the Pantanal biomes, and in the Upper Paraguay Basin;
- Decreased competition with food production areas;
- Indication of areas with agricultural potential (soil and climate) for the sugarcane cultivation in lands with a slope of less than 12%, providing environmentally adequate production with mechanical harvesting.

After the establishment of the SAZ, the NMC drew up two resolutions: No. 3.813 and No. 3.814, both from November 26, 2009, which "condition rural and agro-industrial credit to expand the production and industrialization of sugarcane to the SAZ and prohibits the financing of planting expansion in the Amazon and Pantanal biomes and the Upper Paraguay Basin", among other areas as from October 28, 2009. Under NMC resolutions, The Brazilian Development Bank (BNDES), the main instrument of the Federal Government for long-term financing and investment in all Brazilian economy segments, provided specific government credits and subsidized loans to the sugar and alcohol sector, as long as they follow the SAZ guidelines. Besides, the BNDES created a program to support the renovation and development of new sugarcane plantations (Prorenova), which encouraged the renewal and expansion of sugarcane fields; however, only candidates who met the SAZ specifications were eligible to receive financing.

SAZ has also been used as a criterion to establish the biomass eligibility and the respective volume of biofuel for the RenovaBio program. This eligibility analysis is carried out following the principles of ISO 14065:2015 and in compliance with the requirements of the Brazilian Petroleum Agency resolution No. 758, of November 23, 2018.

According to the SAZ, ≈ 65 Mha are suitable for mechanized sugarcane harvesting, approximately 7.5% of Brazil's total area. In addition, the SAZ contributed to the recognition of the sustainability of the sugar and ethanol sector in the national and international markets. [38]. However, on November 5, 2019, the Brazilian Government revoked the decree that sustained the SAZ through the recent decree 10.084/2019. SAZ was an essential instrument to show the sugarcane industry commitment to forest protection [17]. With the end of the SAZ, it is expected sugarcane to have a direct impact on deforestation.

2.4 Brazilian New Forest Code

The new Forest Code (Law 12.651/2012), which has national coverage, establishes rules for protecting native vegetation, permanent preservation areas, and sensitive areas according to their location (e.g., river springs). It is also designed to protect areas of legal reserve, control and prevent forest fires, and reduce forest exploitation.

In the new Forest Code, the Rural Environmental Registry (CAR) integrates information about rural properties for environmental characterization. The CAR information refers to areas of permanent preservation, legal reserve (remaining native vegetation), and consolidated areas. CAR is mandatory for every rural property in the country and requires the maintenance of an area with legal reserve, according to the following rules: for rural properties in the Legal Amazon, the reserve must be 80% of the property, 35% in savanna areas, and 20% in general fields areas; in the other regions of the country, the legal reserve must be 20% of the area.

The Environmental Regularization Program (PRA), also included in the new Forest Code, contemplates a set of actions to be developed by rural landowners and squatters to promote their properties' environmental regularization. However, such actions under the new regularization policy have reduced the protection of native vegetation to promote easier compliance when compared with the previous policy dating from 1965 [39]. PRAs fall within the scope of each States' constitution, and registration of the rural property in the CAR is mandatory to adhere to this program. The properties that fall under the terms of articles 59 and 60 of the new Forest Code can join the PRA. This option requires the signing of the Terms of Commitment that contain, at least, the commitments to maintain and/or recover degraded or altered areas in Areas of Permanent Preservation (APP), legal reserves, and other areas of restricted use on rural properties. An alternative is to have legal reserves outside the boundaries of their properties. The environmental recovery of rural properties can be achieved using devices such as the Project for Recovery of Degraded and Altered Land (PRADA) or the Environmental Reserve Quotas program (CRA). From the time of signing the Terms of Commitment, sanctions resulting from violations related to irregular suppression of vegetation in APP, legal reserve, and restricted use areas committed before July 22, 2008, are suspended. By participating in this program, administrative sanctions (such as fees) and criminal penalties related to deforestation are extinguished, which brings advantages to rural producers who can thus consolidate agricultural and infrastructure activities in APPs [40, 41].

According to Soares-Filho et al. [42], the total area of native vegetation to be restored went from 50 $\pm$ 6 Mha, under the old forest code (dating from 1965), to 21 $\pm$ 1 Mha with the new Forest Code (of which 78% comprise legal reserve and 22% riparian preservation areas). The new Forest Code has allowed agriculture to expand over natural vegetation, mainly in the Cerrado biome, where only 7.5% of public areas are protected [43].

2.5 Brazilian Nationally Determined Contribution (NDC)

In 2015, at the 21st Conference of Parties (COP 21) in Paris, 195 countries adopted the first-ever universal, legally binding global climate deal as part of the United Nations Framework Convention on Climate Change (UNFCCC) [44]. At COP 21, the signatory countries were required to propose an intended Nationally Determined Contribution (iNDC) to negotiate a protocol, eventually becoming their NDC after the agreement was ratified.

In its NDC, Brazil focuses mainly on the energy sector, and bioenergy plays an important role in GHG emissions reduction. In basically one page of targets and six bullet points, land use and agriculture are mentioned in one bullet point. In contrast, energy is mentioned in the other 4, including measures in the industrial sector regarding energy efficiency and the transport sector. Biofuels and bioenergy have a prominent position in the Brazilian NDC, focused on increasing the share of sustainable biofuels in the Brazilian energy mix to approximately 18% by 2030 [13].

For land use, two quantitative aims are set in the NDC: achieve zero deforestation in the legal Amazon biome by 2030, and restore and reforest 12 Mha for “multiple purposes” by the same year [13]. However, the latest data on deforestation and land use in the country has shown that these two objectives have become harder to achieve each year since 2015 [45, 46].

2.6 RenovaBio

Intending to have 18% of its energy matrix in 2030 based on biofuels in its NDC [13], Brazil created a National Biofuel Policy entitled RenovaBio in 2017 [47]. RenovaBio's main instrument is the establishment of national decarbonization targets for the fuel sector, creating a controlled market for increasing biofuel production and confirming the contribution of renewable fuels to the country's transport energy matrix, including ethanol, biodiesel, biomethane, and renewable jet fuel [48]. Renovabio has a focus on environmental aspects of biofuels (including ethanol) production, rather than focusing solely on energy security as the Proalcool program did.

The existing legislation on RenovaBio shows that it is based on five main supporting measures: GHG emissions reduction targets, decarbonization credits, biofuels certification, biofuel mixing in fossil fuels, and fiscal incentives. In contrast to Proalcool, RenovaBio is concerned about the conversion of native vegetation. To be eligible to take part in the national policy, the producing units' energy biomass can only be counted if it does not comes from a native vegetation conservation area as of 2018 [49]. Therefore, it is still too soon to confirm if this has halted any sugarcane expansion into areas of native vegetation.

3 Sugarcane and other land use trajectories

The trajectories of land use and land cover (LULC) converted to sugarcane have been analyzed using LULC maps produced by the MapBiomas project from 1985 to 2019 for Brazil (Collection 5.0) [46]. MapBiomas uses Landsat-5, Landsat-7, and Landsat-8 satellites data, with a spatial resolution of 30 m, and the Random Forest classifier. The overall accuracy of the maps ranges from 87.7% to 91.2% [46]. The analysis of sugarcane expansion looked at the following former land use and land cover classes: forest, savanna, grassland, pasture, and farming (which involves a combination of other activities including other temporary crops, soybeans, perennial crops, and mosaics of crops and pastures). The difference between the grassland and pasture classes is that grassland formation is a land cover in which there is a predominance of grassy strata, with herbaceous and dicotyledonous shrub species. Pasture (planted or natural) on the other hand is a land use type, which can also be grassland, but cattle facilities and land management practices related to agricultural activities must be evident. [46].

Between 1985 and 2019, sugarcane expanded ≈ 0.3 Mha over forest formation, ≈ 0.2 Mha over savanna formation, and ≈ 0.04 Mha over grassland formation. Figure 2 shows that the rate of sugarcane expansion over native vegetation was fairly constant at the end of the 80s until the end of the 90s, around 3,500 ha per year. From the end of the 1990s until 2009, sugarcane expanded over natural vegetation at its fastest rate (Figure 2), driven by the increase in ethanol consumption [11]. In 2009, there was a decrease in this expansion rate, most possibly driven by the international market's concerns over deforestation and the introduction of the sugarcane agroecological zoning (SAZ) [37, 50], which had been launched that year. In 2011, the sugarcane area began to expand again, possibly caused by increased sales of flex-fuel vehicles and the high sugar prices in the international market [11]. From 2014 onward, there was a decrease in sugar production while ethanol production continued to increase (Figure 1), which did not prevent the conversion of native vegetation to sugarcane but caused the rate of this conversion to decline. This may also have been motivated by Brazil's commitments in the Paris Agreement (NDC). However, in 2019 there was an increase in the conversion of natural vegetation to sugarcane, probably stimulated by the revocation of sugarcane agroecological zoning (SAZ) (Decree 10.084/2019). The revocation of SAZ, which protected areas with natural vegetation, mainly in the Amazon and Pantanal biomes, interrupted the slowdown in deforestation seen in the previous five years caused by the expansion of sugarcane.

Another important trajectory to be analyzed is the expansion of sugarcane over pasture areas. Between 1985 and 2019, ≈ 5.6 Mha of pastures areas were converted to sugarcane (Figure 3). Figure 3 shows that similar to the transition from natural vegetation to sugarcane, the conversion from pastures to sugarcane decreased in recent years; however, in 2019, it increased again. In Figure 4, the Sankey diagram shows the flow of the total areas for each land use and land cover class that have been converted to pasture areas in the 1985-2019 period, and the flow of the total areas converted into sugarcane in the same period. Sugarcane expansion between 1985 and 2019 occurred mainly over pastures, followed by farming areas, which together were equal to ≈ 2.2 Mha of areas converted into sugarcane. The expansion over natural formation (forest formation, savanna formation, and grassland

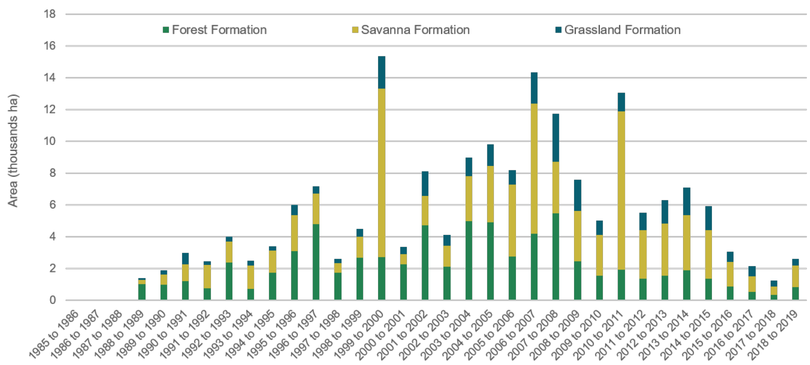

Figure 2: Transitions from natural vegetation (forest formation, savanna formation, and grassland formation) to sugarcane, in Brazil from 1985 to 2019. Source: [46].

formation) was ≈ 0.55 Mha.

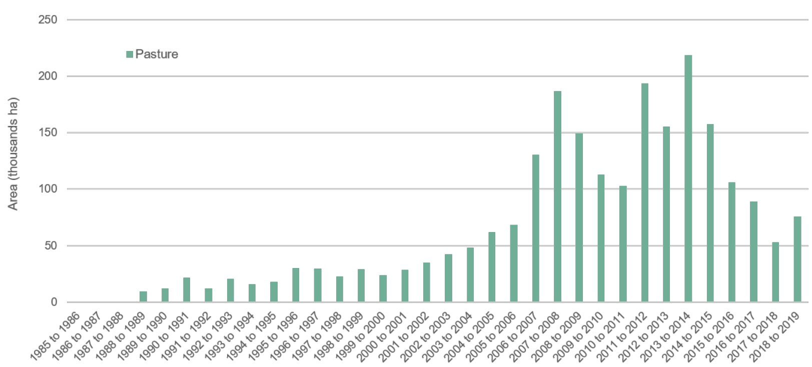

Figure 3: Transitions from pasture to sugarcane, in Brazil from 1985 to 2018. Source: [46].

Several authors warn of the occurrence of indirect land use change (iLUC). Searchinger et al. [51] warned that although biofuels are an alternative to reduce greenhouse gas emissions, it is necessary to be aware of the indirect effects caused by emissions resulting from land use change because of biofuels expansion. Other authors also draw attention to other indirect effects of sugarcane expansion, such as deforestation in the Amazon biome with consequences for the environment and biodiversity [52, 8, 9].

In this sense, it is also important to analyze the trajectories of pasture land in the country. From 1985 until 2019, the main source of land for pasture expansion was forest formation. In this period, ≈ 47.9 Mha of forest and ≈ 19.9 Mha of savanna were converted to pasture (Figure 5). Further expansion of pastures over farming areas add up to ≈ 6.8 Mha. Over grassland formation, pasture has expanded ≈ 2 Mha.

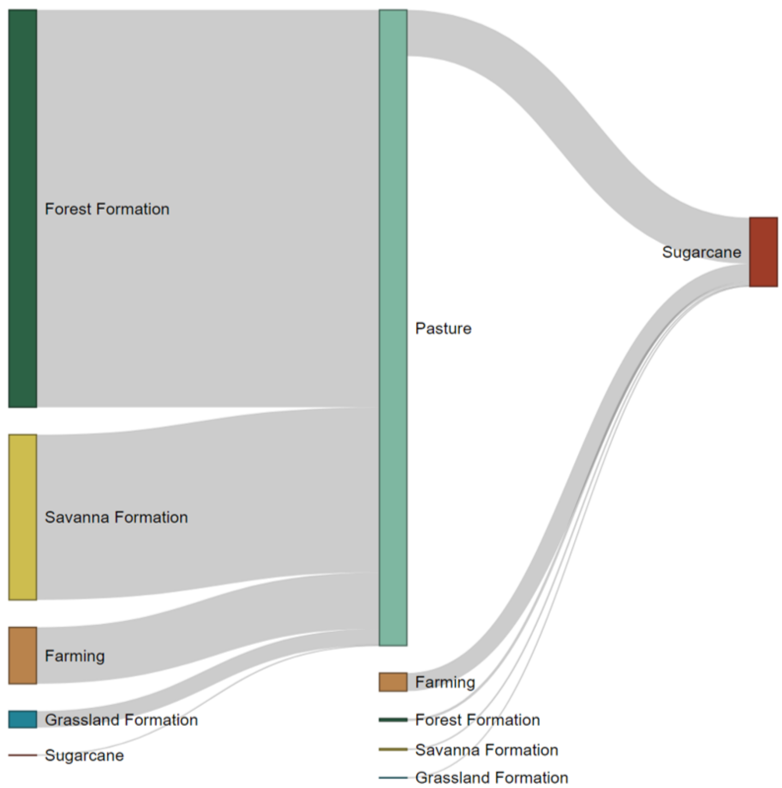

Figure 4: Pasture and sugarcane transitions in Brazil, from 1985 to 2018. Source: [46].

From 2003, there was a decreasing tendency to convert natural vegetation areas (forest, savanna, and grassland formations) to pasture (Figure 5), lasting until 2010. From 2010 onward, an upward trend is observed and the conversion of natural vegetation to pasture reached the period's highest values in 2016 and 2018. Approximately 2.5 Mha of pasture replaced areas of natural vegetation in both years.

The dynamics of land use allowing sugarcane to expand mainly over pasture areas and pastures to expand mainly over natural vegetation shows the indirect effect of the sugarcane expansion and its potential environmental impacts (Figure 4). Lapolla et al. [8] observed that the expansion of cultivated land in other regions of Brazil is pushing the pastures frontier into the Amazon rainforest. This is often accompanied by an increase in the price of potential cropland [53, 54]. The agricultural expansion displaces human and financial capital from old livestock areas to the forest [54]. As investment capital and knowledge of crop production migrate to new areas, land suitable for livestock is deforested. This happens because newly arrived farmers can sell highly valued properties in their previous locations and buy cheap land on the frontier [54].

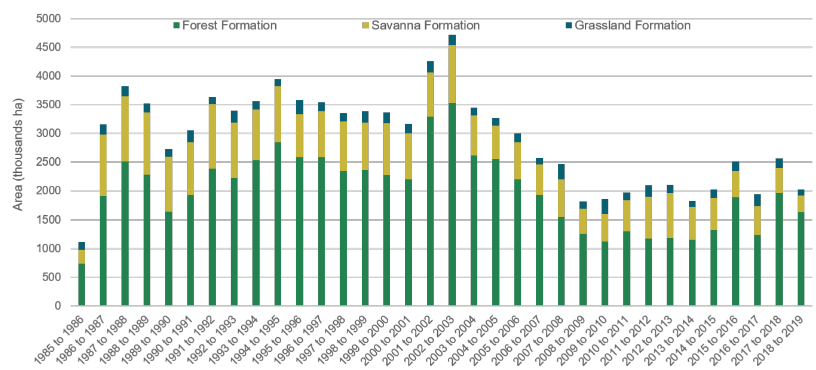

Figure 5: Transitions from natural vegetation (forest formation, savanna formation, and grassland formation) to pasture, in Brazil from 1985 to 2018. Source: [46].

4 The role of land use in the UN Sustainable Development Goals

On September 25, 2015 the United Nations (UN) General Assembly adopted Resolution 70/1 "Transforming our world: the 2030 Agenda for Sustainable Development", containing 17 Sustainable Development Goals - SDG [55]. These objectives aim to end poverty and hunger, safeguard human rights and human dignity, promote peace, and protect the planet from degradation [55].

The Resolution describes seven targets associated with land use and land cover to achieve the UN Sustainable Development Goals (SDGs) [55, 56]. They are: "restore and protect water-related ecosystems (target 6.6); enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management (target 11.3); ensure the conservation, restoration, and sustainable use of terrestrial and inland freshwater ecosystems and their services (target 15.1); promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and increase afforestation and reforestation (target 15.2); combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world (target 15.3); ensure the conservation of mountain ecosystems (target 15.4); Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species (target 15.5)".

Implementing the SDGs and their targets are based on each country's sustainable development strategies and led by Governments, with the support of the United Nations and aligned with the NDCs. In a broad sense, the preamble to Resolution 70/1 requires the cooperation of all stakeholders and persons in the achievement of these SDGs.

In 2019, the Economic Commission for Latin America and the Caribbean (ECLAC) – United Nations, held an open call for case studies on sustainable investment in Brazil. This call received 131 applications from different sectors and regions. Among the case studies sent, 28% were related to land use in agriculture. ECLAC has published these projects on its website and some of them in a report [57, 58].

The study "The sustainable Big Push in the sugarcane production chain" presents the ELO program, created by one of the largest ethanol and sugar producers in Brazil, Raízen [59]. According to the authors, the ELO program has driven the continuous improvement of practices adopted, based on the SDGs, by Raízen's sugarcane suppliers. Among the good practices disseminated by the program is the adoption of certification (Bonsucro and International Sustainability Carbon Certification (ISCC)). The program also aims to achieve economic growth without an increase in GHG emissions or environmental devastation, following Brazilian environmental legislation. One result obtained by this program was that 30 suppliers stopped their agricultural activities in Areas of Permanent Preservation (APP). This application is one example of how much the SDGs can contribute to the sustainability of the ethanol and sugar production chain.

5 How the sugarcane sustainability certification schemes encompass land use

Sustainability certification schemes comprise a set of indicators related to the environment, society, and the economy that have been created by several organizations and some governments used to attest that production of a product or delivery of a service conforms to a comprehensive list of sustainable practices [60]. One important step in creating sustainability certification schemes for biomass and bioenergy was the establishment of the Renewable Energy Directive (RED 2009/28/EC), which is mandatory for the use of renewable energy in the European Union. In 2015 there was an update to the RED (Directive (EU) 2015/1513), with new guidelines for reducing indirect land use change (iLUC). As a result, the use of agricultural land for energy production was limited, and the amount of greenhouse gas emissions was reduced as a consequence. Voluntary certification systems have adjusted their indicators to be consistent with the updated RED [61].

There are eight sustainability certification schemes related to sugarcane production (essentially those related to biomass production or bioenergy production) that are accepted by the European Union [61, 62]. Table 1 shows the number of sugarcane-related producers or operators in Brazil certified by each sustainability certification scheme. The International Sustainability and Carbon Certification (ISCC), the Roundtable on Sustainable Biomaterials (RSB), the Sustainable Biomass Partnership (SBP), the Biomass Biofuel, Sustainability voluntary scheme (2BSvs), and Bonsucro have in total 92 sugarcane producers and processing facilities of sugarcane certified in Brazil. Ramirez et al. [61] documents the details of each certification scheme.

Bonsucro is by far the most commonly adopted certification scheme in Brazil, accounting for 20% of all mills in the country. However, Bonsucro has a limited scope regarding land use and land cover changes, with no consideration given to indirect land use change [61, 69]. It establishes only standards on direct land use change, not allowing any expansion over land with "high biodiversity value" after 2008, which

Table 1: Sugarcane-related certification schemes and number of operators with valid certificates

Certification scheme	Number of certification holders	Source
ISCC	2	[63]
RSB	2	[64]
GBEP	-	
Better Biomass	0	[65]
ISO 13065	-	
SBP	0	[66]
Bonsucro	86	[67]
2BSvs	2	[68]

does not exclude any deforestation or conversion of native vegetation. This happens because, according to the Ministry of Environment, not all areas of native vegetation are considered of "high biodiversity value" [70]. Therefore, Bonsucro could be improved if it included all types of native vegetation instead of limiting consideration to areas of "high biodiversity value".

6 Proposed future directions for sustainable sugarcane production

As suggested by the land use transition data (in Section 3), the indirect impact of expanding sugarcane production on land use is problematic and significant. From the beginning of the 2000s until today, ethanol has been featured as a central piece in Brazilian actions to mitigate climate change. Nevertheless, this environmentally friendly perception of ethanol changed when the indirect effects of land use change came to be recognized, a position argued by Searchinger et al. [51]. Djomo et al. [71] show that the carbon intensity of bioethanol when emissions generated by total direct and indirect land use change are included ranges from a reduction of 29% to an increase of 384% compared to gasoline. This means that iLUC could potentially affect the GHG emissions benefits of biofuels. Besides GHG emissions and loss of carbon stock, several other impacts have been reported in the literature [72]. These include a decrease in dry-season rainfall by 30% in agricultural regions in Brazilian Amazon [73]; shifting the forest equilibrium into a typical savanna bioclimatic envelope [74]; an increase in land surface temperature [75]; higher circulation of viruses [76]; changes to local hydrological cycles [77]; and loss of biodiversity [78], to name a few. These impacts have the potential to affect the fulfilment of several other SDGs than SDG 13 (climate action), such as SDG 2 (zero hunger), SDG 3 (health and well-being), SDG 6 (clean water), SDG 14 (life below water), and SDG 15 (life on land).

Therefore, to guarantee that roughly doubling the country's ethanol production by 2030 will offer GHG reductions and to safeguard the attainment of all SDGs, land use policies have to aim to achieve zero deforestation across the entire agricultural system, as proposed by Daioglou et al. [79], and the reforestation targets must be put into practice. The abandonment of law enforcement and control measures by the Brazilian Government over deforestation can cause any efforts in its NDC related to energy to be insufficient. If the country does not bring deforestation to zero, even tripling ethanol consumption will be marginally sufficient to reach the NDC goals [80]. For that reason, law enforcement and control mechanisms need to be strengthened.

Land use planning mechanisms need to be implemented through agreements between industry, government, and civil society, as a moratorium covering all sugarcane producers, as was the case with the Soy Moratorium [81, 82]. The Soy Moratorium was the first voluntary zero deforestation agreement signed between the soybean producers, civil society, and the Brazilian Government. The goal of this moratorium was to stop the trade of soybeans cultivated in deforested areas from July 2008.

Sugar and ethanol producers must have mechanisms to track the raw material. An alternative would be applying blockchain technology to track and trace the quality of all products along the sugar and ethanol production chain [83].

More specific plans to avoid deforestation and increase productivity should be introduced to decrease the need for more land to be brought into production. This goes beyond the ABC plan, which did not focus on potential productivity increases. Producers should have access to financial programs that reward increases in output while maintaining the same land area in production. This task takes time and effort, but there is extensive evidence to support the idea that productivity increases are possible for Brazil [80].

Credit restrictions should be imposed on producers involved in illegal deforestation, sugarcane areas should be monitored using remote sensing data and integrated with deforestation monitoring data (e.g., using PRODES data [45]), while deforestation inspections must be carried out on private properties through CAR [84, 16, 85, 86].

Six further strategies to achieve zero deforestation in the Brazilian Amazon, that could undoubtedly be applied to the other Brazilian biomes as well, are presented by Moutinho et al. [85]. The six strategies presented by the authors are 1) making socioenvironmentally-friendly investments in infrastructure; 2) expanding production of sustainable commodities; 3) creating sustainable settlements; 4) full implementation of the Forest Code; 5) designating public forests as protected areas and for protection of peoples' rights; and 6) setting out appropriate land governance procedures. The authors explain these measures in depth and break them down into 22 specific actions and 18 ideal perspectives.

Finally, looking from the market side, sustainability certification schemes need to address deforestation from direct expansion of sugarcane as well as the indirect effects. If no deforestation occurs in the country, then the indirect effect will not exist, and ethanol production will be guaranteed to become a net-zero technology.

7 Conclusions

The analysis of public policies' effectiveness on the sustainability of sugarcane products in this study serves as a basis for setting future directions in environmental protection related to the promotion of sustainable agriculture, sugarcane production, and biofuels.

The interest in reducing deforestation and GHG emissions through policies directed at the agricultural sector is relatively new in Brazil. Until 2009, little was mentioned in sugarcane policies about land use change, as exemplified by the Proalcool program, even with direct conversions of natural vegetation to sugarcane of 5.4 thousand hectares on average per year (1985-2009 period).

After the recent attention given to indirect land use change, it has become clear that without the complete cessation of deforestation in the country, regardless of the crop that causes the conversion, the sustainability of biofuels and other agricultural products is not guaranteed. The emissions caused by deforestation will overshadow any GHG emissions reductions from ethanol use in the transport sector.

Our analysis observes that sugarcane expands mainly over pasture areas, which expands mainly over natural vegetation. This shows an indirect effect caused by sugarcane expansion.

Thus, research to increase agricultural productivity in the country, accompanied by control policies that enforce zero deforestation and long-term land use planning, is necessary to guarantee a sustainable agricultural expansion in the future. Looking at the agricultural sector in total and not focusing only on sugarcane is the only way to address the impact of indirect land use change and the damaging GHG emissions that result from it.

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