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Environmental Management

Low Carbon Agriculture Plan: an analysis for the period 1990 - 2018

Plano de agricultura de baixa emissão de carbono: uma análise para o período de 1990-2018

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ABSTRACT

This article aimed to present the goals of the ABC Plan for low-carbon agriculture, and uses the multiple regressions modeling technique to investigate economic activity variables in relation to CO_2 emissions over the period from 1990 to 2018 in all Brazilian states. The results show that the CO_2 emissions in the states, have the same behavior as the land use change timeline, and that public policies and society actions were fundamental to the decrease verified in both CO_2 emissions and the change in use, of the land observed from the year 2004 until 2010. From this year, followed a trend of stability in CO_2 **emissions** and land use change. Another important characteristic is that despite the decrease in the number of deforestations, economic activities continued to grow in the regions, which demonstrates that there may be an increase in production even though the numbers of deforestation and CO_2 emissions are decreasing. This information, strengthen the Low Carbon Agriculture Program, as the main strategy for the development of the productive sector, mainly for sustainable agriculture.

Keywords: Environmental protection policies; climate changes; ABC Plan; Brazil

RESUMO

Este artigo teve como objetivo apresentar as metas do Plano ABC para uma agricultura de baixa emissão de carbono, e utiliza da técnica de modelagem de regressão múltipla para investigar variáveis de atividades econômicas em relação às emissões de CO_2 ao longo do período de 1990 a 2018 em todos os estados brasileiros. Os resultados mostram que as emissões de CO_2 nos estados, tem o mesmo comportamento da linha tempo da mudança de uso da terra, e que políticas públicas e ações da sociedade foram fundamentais para a queda verificada tanto nas emissões de CO_2, como na mudança de uso da terra observada a partir do ano de 2004 até 2010. A partir deste ano, seguiu uma tendência de estabilidade na emissão de CO_2 e na mudança de uso da terra. Outra característica importante é que mesmo ocorrendo uma queda no número de desmatamento, as atividades econômicas continuaram crescendo nas regiões, o que demonstra que pode haver aumento da produção mesmo diminuindo os números de desmatamento e de emissão de CO_2. Essa informação, fortalecer o Programa de Agricultura de Baixa Emissão de Carbono, como a principal estratégia para o desenvolvimento do setor produtivo, principalmente para a agricultura sustentável.

Palavras-chave: Políticas de Proteção Ambiental; Mudanças Climáticas; Plano ABC; Brasil

1 INTRODUCTION

The debate over climate change has intensified in recent decades, supported by various researches. Among them, the First World Climate Conference took place in Geneva in 1979, where climate change were recognized as a problem, but there was no agreement on the cause of it (Leroux, 2005). The first declaration predicting global temperature increases in the 21st century was only approved in 1980 at the Villach conference in Austria (Leroux, 2005).

The Intergovernmental Panel on Climate Change (IPCC), created in 1988, aims to provide scientific assessments on climate change, its implications, and possible future risks, in addition to proposing adaptation and mitigation options. According to the report released by the IPCC, if greenhouse gas (GHG) emissions continue to increase, the world will reach 2°C of warming probably before 2050 and will reach 3°C before the end of the century (Miller, 2021).

In Brazil, the efforts to fight climate change started in 1999 with the creation of the Interministerial Commission on Global Climate Change (CIMGC), which is now called the Interministerial Committee on Climate Change (CIM) (Brasil, 2019). The CIM's competence, in its Art. 2 item I, is to define the guidelines for the Brazilian government's action in climate change-related policies, including the government's action in the United Nations Framework Convention on Climate Change - UNFCCC (Brazil, 2017).

In 2015, Brazil made a voluntary commitment to reduce GHG emissions with 195 other countries to keep the earth's average temperature below 2°C above preindustrial revolution levels by the end of the century, and to promote efforts to ensure that this warming does not exceed 1.5°C (UNFCCC, 2015).

The country has also taken the lead in global environmental negotiations and in the implementation of climate policies in South America, by creating the National Policy on Climate Change (PNMC) established by the Law number 12.187/2009, ratifying the main guidelines and instruments for environmental protection and mitigation of climate change with goals of reducing its GHG emissions between 36.1% and 38.9% in relation to the projected emissions by 2020 (Brazil, 2009). For this purpose, the Ministry of Science, Technology, and Innovations (MCTIC) established the National Emissions Registration System (Sirene[1]), which processes and releases the official annual values of GHG emissions, according to the five sectors that are sources of emissions: energy; agriculture and livestock; land use change (deforestation); industrial processes; and waste treatment (Brazil, 2017). Each of these sectors should develop a plan presenting their contributions to reducing GHG emissions.

In Brazil, the land use change sector is the main source of greenhouse gas (GHG) emissions, emitting approximately 845 Mt CO2e (carbon dioxide equivalent) (46%). According to data from the System for Estimating Greenhouse Gas Emissions and Removals (SEEG), Brazil emitted approximately 2 billion tons of CO2e in 2018 (BRASIL, 2019a; OBSERVATÓRIO, 2018), making it the seventh largest GHG emitter in the world (Brasil, 2019a; Ritchie e Roser, 2017).

The second activity with the highest GHG emissions is the agricultural and livestock sector with 24%, followed by the energy sector with 21% of the emissions (Observatório 2018). These data show that despite Brazil being an industrialized country, its main emissions do not come from energy use, which includes all

[1] Sirene, created by Decree No. 9,172/2017, is a system that makes the results of the National Inventory of Anthropic Emissions by Sources and Removals by Sinks of Greenhouse Gases available, and aims to provide security and transparency to the production of these inventories, as well as to support decision making in government actions related to climate change, including national and international commitments made by Brazil, such as the Paris Agreement and the 2030 Agenda with its seventeen SDGs.

activities that use fossil fuels (407 Mt CO_2e), but rather from land use change through deforestation of forests and agricultural activities (Observatório, 2018).

The sector of land use changes as well as agriculture and cattle ranching are key to the strategic composition of the policies to reduce carbon emissions. Agriculture is a climate-dependent activity, and several studies indicate that climate change could modify Brazilian agricultural production and productivity, threatening growth expectations (Observatório, 2018).

It is within this context that through the PNMC, the Sectoral Plan for Mitigation and Adaptation to Climate Change for the Consolidation of a Low Carbon Emission Economy in Agriculture - the ABC Plan was elaborated, with the objective of promoting the reduction of GHG emissions in agriculture, improving efficiency in the use of natural resources, increasing the resilience of production systems, and enabling the adaptation of the agricultural sector to climate change.

This study presents the ABC Plan goals for low carbon agriculture and uses the multiple regression modeling technique to investigate economic activity variables in relation to CO_2 emissions over the years from 1990 to 2018 in all Brazilian states.

The section 2 presents the goals of the ABC Plan. The proposed analysis method is presented in section 3, then section 4 analyzes the parameters obtained through the multiple regression model and discusses the results. Finally, section 5 concludes the research.

2 THE ABC PLAN

According to the PNMC guidelines in its art.11, the Executive Branch established the sectoral plan for mitigation and adaptation to climate change, encouraging the development of sustainable practices in agriculture that reduce GHG emissions and increase carbon sequestration, as well as in other sectors of the economy (Brasil, 2012). To Berenguer, Erika, *et al*. (2014), tropical rainforests store enormous amounts of carbon, the protection of which represents a vital component of efforts to mitigate global climate change. The ABC Plan created in 2012 is a public policy that presents actions to encourage and monitor the adoption of good practices that prevent deforestation, reduce emissions, and generate resilience to productive systems, without compromising the productivity and growth of the sector, seeking to provide the fulfillment of the voluntary agreement to reduce emissions of Greenhouse Gases (GHG) signed in the Paris Agreement in 2015.

The agricultural and livestock sector is undoubtedly one of the most affected by climate change. Extended periods of drought, heavy rains, high temperatures, pests, and diseases can bring damage to production, livestock, and destabilize the food supply (Observatório, 2018). Seven programs were incorporated into the ABC Plan, six referring to mitigation technologies and one with climate change adaptation actions: Recovery of Degraded Pastures, Adoption of the Crop-Livestock-Forest Integration System (ILPF) and Agroforestry Systems (SAFs); Expansion of the No-till System (SPD); Expansion of the use of Biological Nitrogen Fixation (BNF); Increase in the Area of Planted Forests; Treatment of Animal Waste; and Adaptation to Climate Change.

In each program, several actions have been taken. In the program for adaptation to climate change the adopted strategy is to invest more effectively in agriculture, promoting diversified systems and the sustainable use of biodiversity and water resources, with support for the transition process, production organization, income generation guarantee, research with genetic resources and improvement, water resources, adaptation of productive systems, identification of vulnerabilities, among other initiatives (Brasil, 2012). As for the program for Planted Forests, the strategy is to promote reforestation actions in the country, expanding the reforested area destined to produce fibers, wood, and cellulose, contributing to the capture of CO_2 (Brasil, 2012).

According to Ministry of Agriculture (2019), the ABC Plan has achieved advances by eliminating in the period from 2010 to 2018 between 100.21 and 154.38 million MG of CO_2e.

Over the last few years different scientific researches have been conducted in order to investigate the ABC Plan and the factors that explain CO_2 emissions in the country. A literature summary with investigations of the ABC Plan, including the region of study and which programs of the ABC Plan have been investigated is presented in table 1.

Table 1– Summary of previous studies investigating the ABC Plan

(To be continued)

	Articles	State Region	ABC Plan - Agriculture					
			Recovery of degraded pastures	Crop-livestock-forest integration	No-till farming system	Biological Nitrogen Fixation	Planted Forests	Treatment of animal waste
1	Forage legumes in the recovery of pastures in Brazil	Southeast	x	x		x		
2	Soil carbon stocks in stream-valley-ecosystems in the Brazilian Cerrado agroscape	Midwest	x					
3	Crop-livestock integration systems and climate change policies	Midwest		x				
4	Rural producers perception of climate change and adaptation strategies in Minas Gerais state, Brazil	Southeast			x	x		
5	Transition in environmental governance in the Brazilian Amazon: emergence of a new pattern of socio-economic development and deforestation	North					x	
6	The actions of the Brazilian agricultural sector in the context of climate change negotiations	Brazil	x	x	x	x	x	x
7	Sustainable intensification of Brazilian livestock production through optimized pasture restoration	Midwest	x					
8	Low-carbon agriculture in South America to mitigate global climate change and advance food security	South America, focused on Brazil		x		x	x	x

Table 1–Summary of previous studies investigating the ABC Plan

(To be continued)

	Articles	State Region	ABC Plan - Agriculture					
			Recovery of degraded pastures	Crop-livestock-forest integration	No-till farming system	Biological Nitrogen Fixation	Planted Forests	Treatment of animal waste
9	Increasing agricultural output while avoiding deforestation	Midwest	x			x		
10	Infestation levels of the defoliator Glena unipennaria (Guené e, 1857) (Lepidoptera: Geometridae) in eucalyptus production systems	Midwest		x				
11	Legume-based silvopastoral systems drive C and N soil stocks in a subhumid tropical environment	Northeast		x		x		
12	Expansion of eucalyptus energy plantations under a Livestock-Forestry Integration scenario for agroindustries in Western Paraná, Brazil	South		x				
13	Improving land management in Brazil: A perspective from producers	Midwest	x	x				
14	Why should farmers in Brazil change to Integrated Agricultural Production Systems?	Brazil		x				
15	Future yields of double-cropping systems in the Southern Amazon, Brazil, under climate change and technological development	Southern Amazon		x		x		
16	Adoption and development of integrated crop–livestock–forestry systems in Mato Grosso, Brazil	Midwest		x				
17	Farmers' typologies regarding environmental values and climate change: Evidence from southern Brazil	South		x				
18	Degradation trends based on MODIS-derived estimates of productivity and water use efficiency: A case study for the cultivated pastures in the Brazilian Cerrado	Southeast	x					
19	Achieving food security while switching to low carbon agriculture	Worldwide	x	x		x		
20	Sustainability in the prospective scenarios methods: A case study of scenarios for biodiesel industry in Brazil, for 2030	Brazil	x					

Table 1 –Summary of previous studies investigating the ABC Plan

(To be continued)

	Articles	State Region	ABC Plan - Agriculture					
			Recovery of degraded pastures	Crop-livestock-forest integration	No-till farming system	Biological Nitrogen Fixation	Planted Forests	Treatment of animal waste
21	Challenges and opportunities to advance National Contributions in the agriculture and forestry sector in Latin America: The case of Brazil	Brazil		x	x			
22	Contextual structures and interaction dynamics in the Brazilian Biogas Innovation System	Brazil						x
23	Nationally Determined Contribution on emissions mitigation	Brazil			x			
24	Developing a nationally appropriate mitigation measure from the greenhouse gas GHG abatement potential from livestock production in the Brazilian Cerrado	Cerrado		x				
25	Soil fertility status, carbon and nitrogen stocks under cover crops and tillage regimes	Midwest				x	x	
26	Carbon balance in three silvipastoral systems in Southeastern Brazil	Southeast			x			
27	Can preferential credit programs speed up the adoption of low-carbon agricultural systems in Mato Grosso, Brazil? Results from bioeconomic microsimulation	Midwest			x			
28	Effect of soil tillage and N fertilization on N2O mitigation in maize in the Brazilian Cerrado	Southeast				x	x	
29	Soil improvement and mitigation of greenhouse gas emissions for integrated crop–livestock systems: Case study assessment in the Pantanal savanna highland, Brazil	Midwest			x			x
30	Environmental diagnosis and proposed use of SAF for degraded pasture area	North		x	x			
31	Soil conservation practices and greenhouse gas emissions in Brazil	Brazil			x	x	x	

Table 1 - Summary of previous studies investigating the ABC Plan

(conclusion)

	Articles	State Region	ABC Plan - Agriculture					
			Recovery of degraded pastures	Crop-livestock-forest integration	No-till farming system	Biological Nitrogen Fixation	Planted Forests	Treatment of animal waste
32	Public Policies for Mitigating Greenhouse Gas Emissions in Agriculture: an analysis of the ABC Program	Brazil	x	x	x	x	x	x
33	Economic Assessment of Low Carbon Agriculture Technologies in Cerrado Regions	North	x	x				
34	Crop-Livestock-Forestry Integration in Brazil: a sustainable agriculture strategy based on the concepts of the Green Economy Initiative	Brazil		x				
35	Methane emission factor of open deposits used to store swine slurry in Southern Brazil	South						x
36	A formative evaluation of the ABC Plan	Brazil	x	x	x	x	x	x
37	Recent evolution and potential of Low Carbon Agriculture	Brazil	x	x	x			
38	The role of the banking sector in the environmental quality of agricultural activities: a case study with the ABC Program	Brazil	x	x	x	x	x	x
39	Inverting the carbon footprint in Brazilian agriculture: an estimate of the efects of the ABC plan	Brazil	x	x				
40	Public policies for low carbon emission agriculture foster beef cattle production in southern Brazil	South	x					

Source: elaborated by the authors

Table 2– List of authors and objectives of the papers presented in Table 1

(To be continued)

Article	Author	Objective
1	(Terra *et al.*, 2019)	To present recovery techniques for degraded pastures involving the use of forage legumes and the association with nitrogen-fixing bacteria in order to increase the productivity of pastures, making the system sustainable.

Table 2 –List of authors and objectives of the papers presented in Table 1

(To be continued)

Article	Author	Objective
2	(Wantzen *et al.*, 2012)	To test two hypotheses: (i) the carbon stock of reference sites is higher than that of degraded sites; (STRASSBURG, ICV et al.) (ii) within each valley gradient studied, the carbon stock decreases as distance from the river increases.
3	(Fernandes e Finco, 2014)	To evaluate, through linear programming models, the capacity of ILP systems to become an alternative to traditional land cultivation systems in the north-central region of the state of Mato Grosso.
4	(Pires *et al.*, 2014)	To evaluate the perception of farmers in the state of Minas Gerais, Brazil, towards climate change, as well as to investigate the adoption of adaptive measures.
5	(Tritsch e Arvor, 2016)	To suggest that increased socioeconomic development associated with reduced deforestation activity emphasizes deep changes in the land use frontier and testifies the appearance of an environmental Kuznets curve (EKC).
7	(Silva *et al*., 2017)	To compare the economic and environmental payoffs for farmers from investments in improved pasture restoration versus traditional practices; To understand how the access to ABC credit improves the return on investment; To perform sensitivity analysis of ABC interest rates on key economic parameters and emissions intensity
8	(Sa *et al*., 2017)	To address the potential of LCA (low-carbon agriculture) strategies to mitigate climate change and promote food security in South America.
9	(STRASSBURG, ICV *et al*.)	To inform debates associated with reducing emissions from deforestation and forest degradation as well as sustainable supply chain strategies about the implementation gap and practical solutions at the ground to match increased agricultural productivity and avoided deforestation.

Table 2 –List of authors and objectives of the papers presented in Table 1

(To be continued)

Article	Author	Objective
10	(Pitta, Campelo, & Corassa, 2019)	To evaluate the influence of production systems involving the cultivation of eucalyptus on infestation, as well as the need to control its defoliant Glena unipennaria in order to qualify how sustainable integrated production systems are.
11	(Lira Junior *et al.*, 2020)	To study nutrient stocks in silvipastoral systems that include the lower soil layers, and to assess the possible effects of distance from the trees or shrub components of the system to a depth of 1 m.
12	(Lenz *et al*., 2019)	To explore the expansion of eucalyptus plantations in an LFI scenario for agribusinesses in western Paraná, Brazil.
13	(Latawiec *et al*., 2017)	To systematically evaluate the barriers and conditions surrounding the adoption of good agricultural practices in Brazilian pastures from the perspective of Amazonian farmers involved in their implementation.
14	(Dantas & Moraes, 2016)	To identify potential synergy effects, which are most likely to be exploited by Brazilian farmers. Thereafter, it provides information for the decision making and farmers' understanding of the interaction of the IAPS components.
15	(Hampf *et al*., 2020)	To assess the impact of climate change and technological development on double cropping systems in the southern Amazon by 2040.
16	Gil *et al.*, 2015	To contribute to a deeper understanding of integrated systems in Mato Grosso and to provide information on their potential dissemination by mapping and describing pioneering initiatives, assessing how farmers perceive this new technology, and identifying the determining factors of their adoption.
17	(Foguesatto *et al.*, 2019)	To categorize farmers of different kinds according to their perceptions of environmental issues and climate change in a sample of Brazilian farmers.

Table 2 –List of authors and objectives of the papers presented in Table 1

(to be continued)

Article	Author	Objective
18	(Fernandes *et al.*, 2018)	To analyze, based on MODIS, real evapotranspiration and WUE images, the spatio-temporal degradation dynamics of cultivated pastures found in a study area located in the Brazilian Cerrado biome.
19	(Fan & Ramirez, 2012)	-
20	(Dias *et al.*, 2016)	To provide a method for developing scenarios with sustainability aspects and the case study of scenarios for the Brazilian biodiesel industry with sustainability aspects in the driving forces.
21	(Reis *et al.*, 2017)	To analyze the Intended Nationally Determined Contributions (iNDC), which was presented by Brazil at the United Nations Climate Change Conference held in Paris (NDC, 2015) and became Nationally Determined Contributions (NDC).
22	(De Oliveira & Negro, 2019)	To understand what conditions have enabled or constrained the diffusion of biogas technologies. More specifically, this research applies and adapts the Technological Innovation System framework (Fernandes, Sano et al.) to examine biogas-specific and context-related conditions and their interaction.
23	(De Oliveira Silva, Barioni, Queiroz Pellegrino, & Moran, 2018)	To derive the contribution of the livestock sector to NDC in terms of the degraded pasture area that could potentially be restored cost-effectively (restoration area), over the time frame 2020-2030, under the assumption of meeting the deforestation reduction target and estimating the demand for the ABC program.
24	(de Oliveira Silva *et al*., 2015)	To investigate the cost-effectiveness of the main cattle ranching mitigation measures that are applicable in the Cerrado core (savanna); a region that contains about 35% of Brazil's cattle herd.

Table 2 - List of authors and objectives of the papers presented in Table 1

(to be continued)

Article	Author	Objective
25	(de Carvalho, Marchao, Souza, & Bustamante, 2014)	To evaluate the effect of different cover crops on soil fertility, particularly on carbon and nitrogen stocks in a Red Latos soil under conventional tillage and no-till farming.
26	(Da Rocha *et al.*, 2017)	To evaluate the carbon balance in three silvipastoral systems (SSP), with eucalyptus and brachiaria grass, in Porto Firme, Zona da Mata Mineira, Brazil.
27	(Carauta *et al*., 2018)	To supply detailed information on the effectiveness and efficiency of the ABC Credit Program in providing specific support for the adoption of integrated land use systems.
28	(Campanha *et al*., 2019)	To assess the effect of tillage, with and without nitrogen fertilization, on N2O emissions from soils under dryland corn in the Brazilian Cerrado region.
29	(Buller *et al.*, 2015)	To evaluate the sustainability of an ICLS system in the Brazilian Cerrado, more precisely in the headwaters of important Pantanal rivers.
30	(Bendito *et al.*, 2017)	To diagnose the degradation of a pasture area in the Municipality of Gurupi, through qualitative and quantitative evaluation and to show models of SAFs, to help in the implementation of recovery actions.
31	(Renan Besen *et al.*, 2018)	To clarify relevant aspects about the main GHGs, as well as discuss conservationist management practices with mitigation potentials for these gases.
32	(Gheller, Gazolla *et al.* 2019)	To analyze the ABC Program in terms of granting "green" rural credit, aiming at the sustainability of the production system and the reduction of greenhouse gas emissions (GHG) in agriculture. Specifically, it analyzes which technologies and regions are being invested in and if these funds are adequate to the priority areas and regional environmental demands (Macro-regions and States).
33	(Rodrigues & Melo, 2017)	To compare the economic results of specialized systems (cattle, soy, and corn) with integrated systems (crop-livestock and cattle-forest).

Table 2 –List of authors and objectives of the papers presented in Table 1

(conclusion)

Article	Author	Objective
34	(Dos Reis *et al.*, 2016)	To insert the proposal of agriculture organization based on the concepts of Crop-Livestock-Forest Integration (ILPF) in the scope of discussions related to the need to transform the current productive model.
35	(Sardá *et al*., 2018)	To establish a methane emission factor baseline for swine manure management, when considering the current practice of storing solid manure in two parallel open tanks, in Southern Brazil.
36	(Wander *et al.*, 2016)	To make a normative evaluation of the ABC Plan with the intention of making a diagnosis of the program's current implementation phase, to elaborate an analysis of the resources destined to it, and how they are applied as well as to what types of activities they are allocated.
37	(de Magalhães & Júnior, 2013)	To evaluate the goals of this Program according to the potential to reduce emissions and its operationalization.
38	(Do Nascimento *et al.*)	To understand the influence of the ABC Program on the environmental performance of private farms through a methodological triangulation between literature research, document analysis, and interviews.
39	Martins *et al.*, 2018)	To estimate the GHG emissions from the agriculture and cattle ranching sector considering the adoption of three low carbon emission (LCT) technologies - pasture recuperation, crop-livestock integration (LCI), and crop-livestock-forest integration (LCIFS).
40	(da Costa *et al*., 2019)	To evaluate the impact of two complementary public policies, one federal, the ABC Program, and one from Santa Catarina, the Catarina Beef Development Program.

Source: elaborated by the authors

3 METHODOLOGY

For the development of this research, exploratory-descriptive and experimental research was used, using the bibliographical and documental research procedure for data collection. The bibliographical research was the basis for the development of the theoretical framework, since the information needed to develop the research came from the scientific and technical literature available in public materials such as articles, manuals, websites, the Federal Constitution, and complementary legislation. The documentary research was based on different documents and involved secondary data analysis. As from the data survey on the sectorial plan for mitigation and adaptation to climate change in the Web of Science and Scopus databases, as well as in the Google Scholar platform, it was aimed to identify the ABC Plan goals for a low carbon emission agriculture and climate change mitigation adopted in Brazil. This search was performed in May 2021 and the search terms were: "Plano abc" AND "Brazil" OR "ABC Plan" AND "Brazil" OR "Low carbon agriculture" OR "Low carbon agriculture", 72 articles were found in the Web of Science database, 28 in Scopus, and 34 in Google Scholar. With the help of EndNote software, 67 duplicate articles were excluded, leaving 67 for analysis. After reading the title, abstract and key words, 40 articles were selected that were in line with the sectorial plan for mitigation and adaptation to climate change. For the experimental analysis, multiple regression analysis was used. We investigated variables of economic activities in relation to emissions of carbon dioxide equivalent (CO_2e), over the years from 1990 to 2018 for the 26 Brazilian states and the Federal District. The data were available on the Climate Observatory's System of Estimates of Emissions and Removals of Greenhouse Gases (SEEG) website. To adjust the multiple regression model, the R software was used. The following section presents the results obtained, as well as the research discussions.

4 RESULTS AND DISCUSSION

The estimated data of economic activities in relation to CO_2 emissions in the 26 Brazilian states and the Federal District are presented in Table 3. These data correspond to the analysis performed for the period from 1990 to 2018.

Table 3 –Estimated economic activities in relation to CO_2e emissions in tons in the period of 1990 – 2018

(To be continued)

Variables	n	mean	sd	Median	Min	max	skew	kurtosis
Total consumption of synthetic nitrogen fertilizer (t)	773	86.402,45	150.151,5	14.643	28,1	72.2590	2,22	4,21
Alcohol Production (l)	604	877.536.700	2.351.783.000	140.640.000	153.000	16722480000	4,26	18,89
Beef Production (t)	640	23.0859,1	287.281	81.272,95	53,8	1445057	1,57	1,85
Milk Production (l)	781	907.416.600	1.518.490.000	363.272.000	1.685.000	9370470000	3,1	10,89
Corn Production (t)	782	1.803.448	3.376.233	257.169,5	180	29942320	3,38	15,55
Soybean Production (t)	508	3.024.068	4.935.700	1.076.300,5	4	31608560	2,71	8,5
Beef Cattle Herd (c)	783	6.219.145	7.010.447	2.151.048	49.923	29743000	1,23	0,56
Dairy Cow Herd (c)	783	738661,8	998.409	411.262	4.311	5850737	2,82	9,02
Liming (ha)	354	1.769,76	1.820,00	1.218,15	20,00	17.800,00	2,68	16,79
Annual Deforestation Amazon (ha)	255	155.857,65	219.000,00	59.500,00	700,00	1.180.000,00	2,08	4,14
Annual Deforestation Caatinga (ha)	290	34.164,62	38.100,00	19.033,33	201,19	156.000,00	1,57	2,15
Annual Deforestation Cerrado (ha)	338	114.397,88	126.000,00	96.609,90	5,21	661.000,00	2,03	5,51
Annual Deforestation Atlantic Forest (ha)	354	4.484,45	7.120,00	952,00	3,00	35.600,00	2,33	5,66
Annual Deforestation Pampa (ha)	25	35.245,55	35.900,00	33.514,37	100,00	114.000,00	0,93	-0,26

Table 3–Estimated economic activities in relation to CO_2e emissions in tons in the period of 1990 – 2018

(Conclusion)

Variables	n	mean	sd	Median	Min	max	skew	kurtosis
Annual Deforestation Pantanal (ha)	58	36.350,44	14.900,00	32.490,40	8.921,00	63.800,00	0,32	-0,99
Total land use change (ha)	777	120.362,1	199430,8	39325,6	11	1832360	3,7	19,24
Total industrial processing	722	4.022.952	6841440	1424973,52	118,97	40183690	3,08	10,24
CO2e GWP (t)	783	80.829.630	114605600	45955236,28	1053773,85	1155350000	3,87	22,08

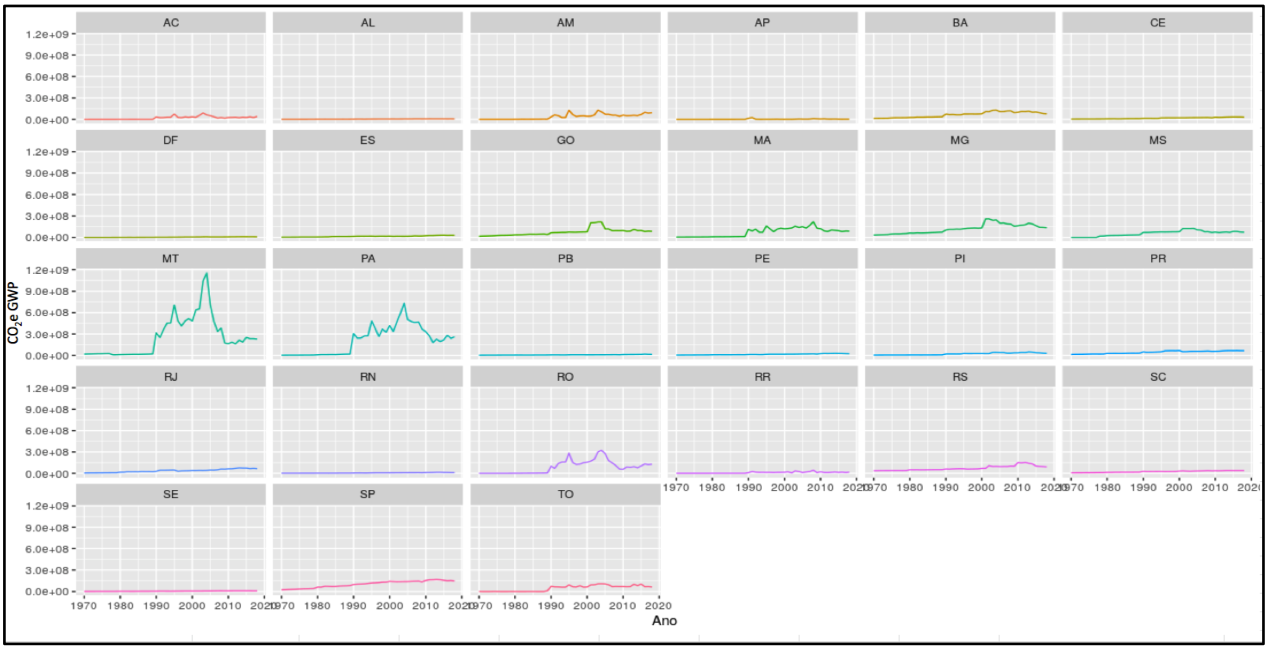
(t) tonne; (l) liter; (c) head; (ha) hectare; Source: elaborated by the authors

The results show that, on average, land use change and forestry in Brazil is approximately 120,362.14 HA, indicating that deforestation is the main source of change in land use. Deforestation is considered to be the main responsible for the high emission of CO_2 in Brazil, as shown in Figure 1. The main sources of emissions from agriculture and cattle raising are attributed to the cattle herd, which releases high amounts of methane (CH_4) due to the ruminal fermentation of the animals, followed by the dairy cattle herd. Other agricultural activity with high CO_2 emission is the consumption of synthetic nitrogen fertilizers on the soil with increasing emission of nitrous oxide (N_2O) into the atmosphere.

Figure 1 shows that the highest CO_2 emissions were found in the states of Mato Grosso (MT), Pará (PA), Rondônia (RO), Minas Gerais (MG), Maranhão (MA), Goiás (GO), Amazonas (AM), Bahia (BA), Rio Grande do Sul (RS), São Paulo (SP), Tocantins (TO), Acre (AC), and Mato Grosso do Sul (MS). Most of these states are part of the Amazon and Cerrado biomes. The correlation analysis of economic activities and CO_2 emissions in Brazil confirmed that the main CO_2 emissions come from land use change and forestry and from the agriculture and cattle raising sector as shown in Table 4.

The correlation data of economic activities and CO_2 emissions in Brazil (Table 4), show that there is a strong correlation with the total consumption of synthetic nitrogen fertilizer in relation to emissions of CH_4 and N_2O. It is also observed that the activities related to beef production and beef cattle herd presented a very strong correlation with the emission of CH_4 and N_2O, while the activities related to land use change with the annual deforestation of the Amazon, the annual deforestation of the Pampa and the total land use change presented a strong correlation with the CO_2 emission variables.

Figure 1–Time series of CO_2 emissions



Source: elaborated by the authors

Table 4–Correlation of economic activities and GHG emissions from 1990 – 2018

(To be continued)

Activities	Emissions			
	CH_4	CO_2e GTP	CO_2e GWP	N_2O
Total consumption of synthetic nitrogen fertilizer	0,715	0,173	0,248	0,811
Sugar Production	0,348	0,064	0,102	0,415
Alcohol Production	0,413	0,085	0,129	0,490
Sugarcane Production	0,386	0,074	0,116	0,453
Beef Production	0,828	0,381	0,453	0,822

Table 4 –Correlation of economic activities and GHG emissions from 1990 – 2018

(Conclusion)

Activities	Emissions			
	CH_4	CO_2e GTP	CO_2e GWP	N_2O
Milk Production	0,624	0,118	0,187	0,662
Corn Production	0,592	0,135	0,198	0,681
Soybean Production	0,618	0,300	0,353	0,676
Beef Cattle Herd	0,928	0,517	0,591	0,879
Dairy Cow Herd	0,679	0,190	0,259	0,695
Annual Deforestation Caatinga	0,014	-0,088	-0,068	0,057
Annual Deforestation Cerrado	0,396	0,524	0,534	0,299
Annual Deforestation Atlantic Forest	0,266	0,320	0,315	0,288
Annual Deforestation Pampa	0,872	0,983	0,980	0,736
Annual Deforestation Pantanal	-0,017	0,581	0,565	0,013
Total land use change	0,519	0,921	0,913	0,473
Total industrial processing	0,493	0,116	0,167	0,522
Total Waste	0,499	0,028	0,083	0,486

Source: elaborated by the authors

The correlation data of economic activities and CO_2 emissions in Brazil (Table 4), show that there is a strong correlation with the total consumption of synthetic nitrogen fertilizer in relation to emissions of CH_4 and N_2O. It is also observed that the activities related to beef production and beef cattle herd presented a very strong correlation with the emission of CH_4 and N_2O, while the activities related to land use change with the annual deforestation of the Amazon, the annual deforestation of the Pampa and the total land use change presented a strong correlation with the CO_2 emission variables.

The Table 5 presents the correlation of the variables of economic activities and CO_2 removal in Brazil. Note that the variables do not present a strong correlation with removal, only deforestation in the Pampas presented a negative correlation of -0.674. This indicator is related to the values observed only in the state of Rio Grande Sul, because the Pampa is the only one of the six Brazilian biomes that is present only in this state.

According to WENZEL (2018), the countryside landscape that dominated 63% of Rio Grande do Sul's territory and which characterizes the Pampa, is currently with more than half of its area degraded, representing the second most devastated biome in Brazil. This deforestation occurs mainly for soybean production in the state.

Table 5 –Correlation of economic activities and GHG removal from 1990 – 2018

Activities	Removal CO_2e GWP
Total consumption of synthetic nitrogen fertilizer	0,090
Sugar Production	0,077
Alcohol Production	0,080
Sugarcane Production	0,082
Beef Production	-0,131
Milk Production	0,122
Corn Production	0,035
Soybean Production	-0,025
Beef Cattle Herd	-0,151
Dairy Cow Herd	0,091
Liming	-0,407
Annual Deforestation Amazon	-0,274
Annual Deforestation Caatinga	0,198
Annual Deforestation Cerrado	-0,218
Annual Deforestation Atlantic Forest	-0,217
Annual Deforestation Pampa	-0,674
Annual Deforestation Pantanal	-0,124
Total land use change	-0,297

Source: elaborated by the authors

For the multiple regression analysis, the data was transformed into logarithms, which resulted in data with an approximately normal distribution. In this case, the logarithm is applied to both the dependent variable (CO_2) and the independent variables, which results in a model known as log-log. Non-significant variables and variables containing VIFs greater than 5 were excluded. Based on this analysis, the equation (1) was obtained to explain the Brazilian CO_2 emissions:

$$\log(CO_2) = \beta_0 + \beta_1 \log(TUT) + \beta_2 \log(PCB) + \beta_3 \log(PS) + \beta_4 \log(TPI) + \beta_5 \log(PAC) \quad (1)$$

The model proposed by the multiple linear regression Equation (1) to explain CO_2 emissions suggests the following variables: land use change (TUT), beef production (PCB), soybean production (PS), total industrial production (TPI) and sugar production (PAC). The model was analyzed using only the total land use change and forests variable which showed an R^2 of 0.4. On the other hand, the model with land use change and beef production presented an R^2 of 0.65 and the model of equation 1 presented an R^2 of 0.71, which means that soy production, industrial production and sugar production collaborated with only 0.06 to improve the model, however it presented itself as the best model, as can be seen in Table 6.

Table 6 –Inclusion of the TUT variable with the year variable

Model	**R^2**	**df**	**AIC**	**BIC**
CO_2 ~ TUT	0,40	3	2184,19	2198,15
CO_2 ~ TUT + PCB	0,65	4	1337,73	1355,57
CO_2 ~ TUT + PCB + PS	0,75	5	629,95	650,41
CO_2 ~ TUT + PCB + PS + TPI	0,76	6	571,57	595,86
CO_2 ~ TUT + PCB + PS + TPI + PAC	0,71	7	403,34	428,86

Source: elaborated by the authors

It is noticed that there is a difference in the R^2 value of the model CO_2 ~ TUT + PCB + PS + TPI + PAC of 0.71, from the model excluding the Sugar Production variable (PAC) which is 0.76. This difference occurs since not all states have results for sugar production, thus the regression model considers fewer lines for the analysis, yet the AIC and BIC values were better.

The regression results of the model estimated in equation (1), presented statistical significance (F = 137) with a p-value less than 0.00001. The model presented the R^2 value equal to 0.71, indicating that approximately 71% of the log variance explains the CO_2 variable, and all the coefficients of the independent variables are statistically significant, as shown in Table 7.

Table 7 –Multiple Regression Model for Variable Selection

Variable	**Estimate (β)**	**Standard error**		**Pr(>|t|)**
(Intercepto)	9,80626	0,37629	26,06	< 2e-16***
log_TUT	0,37259	0,02446	15,23	< 2e-16***
log_PCB	0,19143	0,03231	5,924	9,27E-09***
log_PS	0,05742	0,01184	4,852	2,05E-06***
log_TPI	0,04389	0,01045	4,199	3,62E-05***
log_PAC	0,04106	0,01731	2,372	0,0184*

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Source: elaborated by the authors

It is noticed that there is a difference in the R^2 value of the model CO_2 ~ TUT + PCB + PS + TPI + PAC of 0.71, from the model excluding the Sugar Production variable (PAC) which is 0.76. This difference occurs since not all states have results for sugar production, thus the regression model considers fewer lines for the analysis, yet the AIC and BIC values were better.

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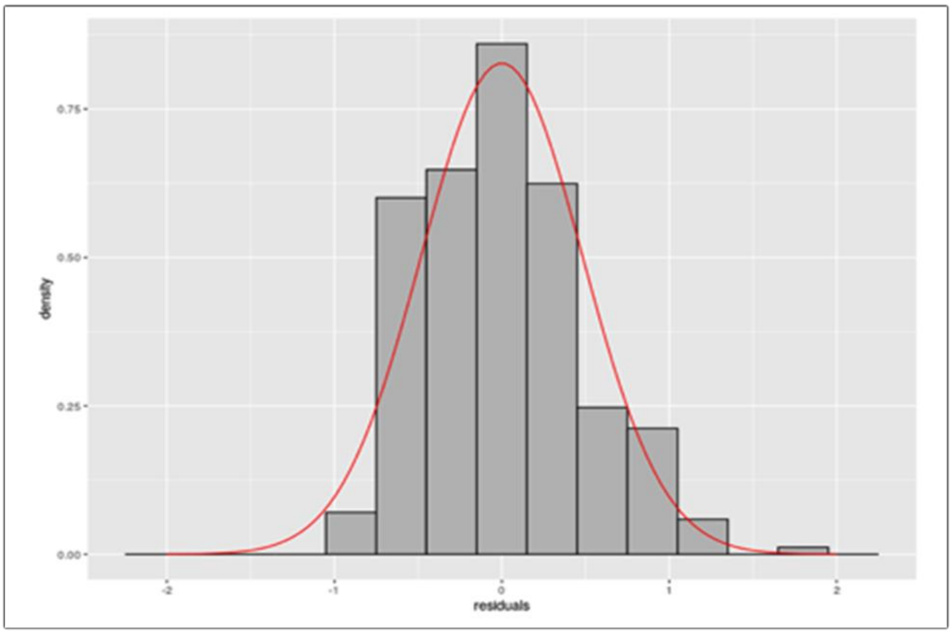
As the model assumes, all β coefficients were highly significant, with only β5 coefficient related to sugar production showing significance less than 0.05, while the other variables showed significance less than 0.001.

The parameters can be interpreted as follows, assuming that all the values of the explanatory variables are equal to 1, the value of log(xi) = 0, the expected value for CO_2 is equal to exp (9.80626), now assuming that only the TUT variable increases by 1% of the mean, a variation of 0.37% in the CO_2 variable is expected. This interpretation occurs because of the application of the logarithmic transformation of the variables. The histogram of the distribution of the residuals is shown below, the mean of the errors was approximately zero and its distribution is close to the normality pattern as displayed in Figure 2.

Figure 2 - Histogram of model residual



Source: elaborated by the authors

The result shows the strong influence of the response variables on CO_2 emissions, among the variables selected for the model. It is observed that the variable with the greatest explanatory power is land use change, followed by beef production, as can be seen in the Table 2. It was also noted that emissions occur in a localized way in Brazil, and the states with the highest CO_2 emissions are the northern and central western states, which are part of the Amazon rainforest and Cerrado. Comparing the variables by state (Figure 3), it is observed that the state of Mato Grosso is the largest emitter of CO_2, where the variable land use change follows the values of CO_2 emission. The graph is in logarithmic scale, it can be seen that in the period from 1990 to 2004 there was an increase in all variables, and from 2004 to 2010 there was a reduction in both CO_2 emissions and total land use change. However, it is noted that other variables did not have the same behavior in Mato Grosso, for example, the agricultural production variables, even with a reduction in CO_2 emissions continue to rise.

Figure 3 - Time series of CO_2 emissions

Source: elaborated by the authors

This exact same behavior occurred in the states of Pará and Minas Gerais. However, this behavior was observed in a different way for the states of São Paulo and Santa Catarina. One of the reasons is that in these states there were not large numbers of CO_2 emissions and land use change, because they have different economic characteristics than the states of the North and Midwest. It can also be observed that the line that represents the industrial production presented strong variation in the values, such variation may have occurred due to some addition of a product or production, or even because of a different measurement methodology. To calculate the regression, the values of the entire industrial production of Brazil were considered.

5 CONCLUSION

This study investigates the goals of the ABC Plan for low carbon agriculture and uses the multiple regression modeling technique to investigate economic activity variables in relation to the CO_2 emissions over the period from 1990 to 2018 in all 26 Brazilian states and the Federal District. With the multiple regression analysis, it was observed that some economic activity variables have a correlation with CO_2 emissions. It can be understood that the characteristics of the states have some significant differences and that the variable that best helps to explain CO_2 emissions in the Brazilian states is the variable land use change followed by beef production, which are economic activities concentrated in the northern and central western regions. The results show that if there is a 1% increase in the average of the land use change variable (TUT), a variation of 0.37% in CO_2 emissions is expected, while the beef production has a variation rate of 0.19%, soybean production 0.057%, total industrial production 0,043% and sugar production 0,041%. From 1990 to 2004 there was a strong growth of CO_2 emission, which was also followed by the land use change and the other production variables, so that the economic variables can be helpful in explaining the CO_2 emission. However, since 2004 there was a drop in CO_2 emissions in which public policies and actions by society and the private sector were fundamental for that drop, both in CO_2 emissions as well as in the TUT, starting in 2004 and continuing until 2010. From this year on, a trend towards stability in CO_2 emissions and total TUT was observed.

The present study showed that CO_2 emissions have the same behavior as the TUT timeline. This means that when there is a reduction in land use change, there is also a reduction in CO_2 emissions. Similarly, we can say that large volumes of CO_2 emissions that occur in certain regions of the country, such as the northern and central western regions of the country, occur due to land use change, which in this case is driven by deforestation. This result can be seen in the graph of the time series of emissions. The state of Mato Grosso and the state of Pará, were the largest contributors to the CO_2 emissions in Brazil, Figure 3. Another important characteristic is that even though there was a drop in the number of deforestations, the production variables continued to rise for these same regions, which shows that there can be an increase in production, despite the decrease in the numbers of deforestation and CO_2 emissions. Such information strengthens the Low Carbon Emission Agriculture Program as the main strategy for the development of the productive sector, especially for sustainable agriculture. But, as soon as new information, databases on fires and deforestation are available for consultation, these findings should be further analyzed and compared, due to the large number of fires and deforestation that occurred in the country in 2020.

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