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Analysis of the Profile of the Greenhouse Gas Emissions in Brazil

Fábio de Oliveira Neves[1], Arlinda de Jesus Rodrigues Resende[2], Plinio Rodrigues dos Santos Filho[3] & Breno Régis Santos[4]

[1] Department of Environmental Science. Exact Science Institute. Federal University of Alfenas, Alfenas, Minas Gerais State, Brazil. Orcid: orcid.org/0000-0003-1751-2064

[2] Department of Environmental Science Institute of Natural Sciences. Federal University of Alfenas, Alfenas, Minas Gerais State, Brazil. Orcid: orcid.org/0000-0001-9287-7376

[3] Department of Biochemistry. Institute of Biomedical Sciences. Federal University of Alfenas, Alfenas, Minas Gerais State, Brazil. Orcid: orcid.org/0000-0001-8530-1977

[4] Department of Environmental Science. Institute of Natural Sciences. Federal University of Alfenas, Alfenas, Minas Gerais State, Brazil. Orcid: orcid.org/0000-0002-3980-9013

Correspondence: Fábio de Oliveira Neves, Department of Environmental Science. Exact Science Institute. Federal University of Alfenas, Alfenas, Minas Gerais State, Brazil. E-mail: fabiooneves@gmail.com.br

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Abstract

The number of debates on sustainability and the emission of gases (GHG), that potentiate the greenhouse effect, have grown in recent years, mainly regarding structural changes in the organizational dynamics of society. Particularly in Brazil, which has an extensive territorial area and native vegetation, emission of greenhouse gases is responsible for harmful socio-environmental effects both externally and internally to the country. Thereby, this study aimed to characterize the GHG in Brazil and identify which sustainable factors influence GHG emissions and how these factors correlate with the variations in temperature between 1990 and 2022. For that, multiple linear regression models were used to develop the regression model and canonical correlation analysis to verify how the adjusted factors behaved with the temperature in this period. The results of this study show that the four adjusted indicators are of economic origin and closely related to the type of economic production in Brazil. Each indicator has a similar correlation with temperature variations. This GHG profile helps public decision makers gain an overview, particularly in relation to the drastic temperature changes and current weather conditions. It is expected that this work will have theoretical implications for a new line of research to be deepened, which can develop practices that allow public managers to plan how to reduce the greenhouse gases indicators analyzed in this research. Therefore this study can contribute as a research tool in the control of greenhouse gas emissions in Brazil.

Keywords: greenhouse gases, sustainable factors, statistical models

1. **Introduction**

The international community has pointed out that, in order to avoid further damage as a result of climate change, the global average temperature increase should be maintained at least below 2 °C until the end of this century (compared to pre-industrial levels). Therefore, several groups of researchers have analysed the difference between the emission levels needed to achieve this objective and the sustainable political synergy among stakeholders (productive systems, governments and the population) (Conte Grand, 2016; Den Elzen & Höhne, 2008; Lahsen & Ribot, 2022; UNEP, 2022). It is suggested that the difference is substantial; and, until the end of this period, it will require reductions in greenhouse gas (GHG) emissions of between 50% by 2050. In Brazil, this reduction would need to be around 43% by 2030 (Ministry of the Environment of Brazil, 2022; Morton et al., 2016).

Coupled to this problem of the increase in global temperature, which arises from the emission of greenhouse gases, is sustainability in its broadest concept, as proposed by Brundtland (1987): “economic growth linked to social justice and environmental quality”. The concept of sustainability emerges as a tool of elements to combat global climate change and has a broad perspective of facing global environmental and social disasters. With this, tackling GHG emissions is one of the main global challenges that society faces so that a socio-environmental multi-systemic collapse does not occur. As highlighted in the literature (Conte Grand, 2016; Den Elzen & Höhne, 2008; Z. Liu, Zhang, Zhang, & Zhu, 2020; Morton et al., 2016; UNEP, 2022), combating the variation in Earth's temperature involves actions to reduce GHG emissions and thus reduce extreme weather events.

Extreme climate change through a global economic growth model is resource intensive and tends to be insensitive to negative global externalities due to its long-term impacts. Moreover, the concept of global sustainability embodied in the necessary reduction of the level of pollutants released into the atmosphere can be interpreted as a matter of inter-managerial distribution as it affects the well-being of future generations (Duro, 2016; Neumayer, 2010; Reed, Wehner, & Zarzycki, 2022)). However, at the same time, the excessive consumption of resources, given their finite nature, makes it necessary to consider the problem of sustainability as an intra-management asset (multiple management) (Anand & Sen, 2000). Thus, sustainability must incorporate not only global elements in terms of the planet, but also, to a large degree, equitable distributions (UNEP, 2006). Thereafter, national governments will decide which types of financial support will be most relevant to the depletion of natural resources by the local population (Duro, 2016; Harris et al., 2018; Reed et al., 2022).

Environmental factors of anthropic or natural origin also leave a neuralgic stain on the levels of emissions of greenhouse gases, either through the emission of pollutant gases into the atmosphere, especially those resulting from the burning of fossil fuels, such as the burning of diesel oil and gasoline by vehicles in major cities that has contributed to the greenhouse effect, or emissions released through agriculture (fertilizer use), livestock farming and waste, or even the emissions that belong to the natural complex, such as the short-term emissions of volcanic origin (Alam, Murad, Noman, & Ozturk, 2016; Bezerra et al., 2022; Fuglestvedt, Samset, & Shine, 2014; Miranda, Silva, & Juvanhol, 2022; van den Bergh & Botzen, 2015)

Given this, perhaps the most striking aspect of planet Earth is its dynamics, which occur in all systems of economic growth model and that relate to the factors of an environmental nature, albeit in different orders of magnitude. This fact is particularly present in atmospheric processes. In association with these natural dynamics, there is the human capacity to disturb the environmental system, indisputably evidenced in the last decades, which is changing the physical-chemical balance of the planet and its surface, as well as the speed of the processes. This modification of the global environment has taken place abruptly, although the processes involved are only partially understood. The anthropogenic changes are not clearly distinguishable from those of natural order (International Panel Climate Change, 2019). This is an unprecedented situation, since it is expected that, in one generation, the environment that sustains life and physical processes will change more rapidly than in any other period of human history (Prado-Lorenzo, Rodríguez-Domínguez, Gallego-Álvarez, & García-Sánchez, 2009; Reis et al., 2022; Villén-Pérez, Anaya-Valenzuela, Conrado da Cruz, & Fearnside, 2022).

Nevertheless, in connection with the reduction of greenhouse gas emissions together with the criteria and principles of sustainability proposed by (Brundtland, 1987), in the last decades, some developing countries such as Brazil have come to be among the largest emitters of gases that cause the greenhouse effect. Brazil is now occupies the 5th largest emitter of GHGs in the world, which increases its responsibility regarding the generation of problems and their possible solutions. Thus, in 2009, Brazil signed, for the first time, the National Policy on Climate Change, which is a commitment, both internationally and domestically, to control its GHG emissions (Ministry of the Environment of Brazil, 2022).

GHG emissions, together with the principles of sustainability, begin to be assessed by quantitative indicators (Alam et al., 2016; Aquila et al., 2016; Bennetzen, Smith, & Porter, 2016; Cardozo, Bordonal, & La Scala, 2016; Conte Grand, 2016; Fujii & Managi, 2015; Olabi et al., 2022). So far, the most employed are those linked to the economic, anthropic (social) and environmental sectors. All these indicators portray their influence on reducing or increasing the emissions of greenhouse gases. The influence of factors related to the three aspects of sustainability, even in expansive economies such as Brazil, is not virtuous in itself, if it is not evaluated in conjunction with the greenhouse gas production target (Hagen et al., 2022; van den Bergh & Botzen, 2015).

Studying how these sustainability factors influence the emission of GHGs and how they are responsible for the increase in temperature in Brazil is justifiable due to the occurrence of numerous severe weather events that have occurred in recent years, such as the increasingly acyclic temperature variations during the different seasons of the year. The development of analyses showing the relationship between sustainability and GHG emissions is important in order to give greater direction in the specific actions needed to reduce the temperature in Brazil, thus, working towards the resolutions of environmental conventions such as the IPCC, IEA and COP.

In this context, this work proposes the analysis of the profile of the emission of greenhouse gases in Brazil, in addition to the verification of which economic, environmental and social factors influence the GHG emissions, and how these adjusted indicators relate to the temperature variations witnessed over the last 22 years. Canonical correlation analysis (CCA) was used to analyze the correlations between the adjusted factors in the statistical model and temperature variations. For this analysis, the quantitative coverage was used as a research method, through a multiple regression model. The R software was used as a tool for modelling industrial production in Brazil.

For the rest of the article, in addition to this introduction, economic, social and environmental dynamism was also analyzed, with sustainability as its central theme (Section 2). In the third section, we developed the description of the research methods studied. In Section 4, there is an extensive discussion of the multiple regression model for sustainability factors in GHGs and how they correlate with temperature variations in the past. In Section 5, the main sustainable policy implications are verified and, finally, in Section 6, the main conclusions and future perspectives are developed in regards to the analyzed results.

2. Economic, Social and Environmental Dynamism

Climate change is considered one of the most difficult negative externalities to deal with since its global dimension makes it more complex and uncertain than most of the other externalities that occupy the economic theory. Its causes and their possible consequences are related to almost all economic activities and affect all people, countries and their ecosystems and biodiversity. The uncertainties about the possible consequences of climate change are considerable, and the time horizon, over which the current emissions will be relevant, is long; Therefore, the usual tools employed in decision-making when facing uncertainties may not be appropriate (Dietz & Maddison, 2009; Ribeiro et al., 2021). It is in this context that modeling and comparing risks and uncertainties related to climate change has been one of the greatest challenges experienced by many experts in recent times, since it has the objective of offering policy recommendations to combat global warming to decision makers and society as a whole (Ribeiro et al., 2021). Cost-benefit analyses of investments in climate change mitigation or adaptation to climate change necessarily begin with assumptions about the pattern of future emissions, the expected warming pattern from these emissions and the behaviour of other variables in the face of changes in temperature (sea level, changes in GHG concentration, acidification of the oceans, changes in photosynthesis, for example), and in the face of the indirect effects of these factors, such as changes in the evapotranspiration of ecosystems and the consequent feedback from the climate (Akadiri, Adebayo, Riti, Awosusi, & Inusa, 2022). Subsequently, we seek to translate the consequences foreseen by the models into economic terms. Decisions regarding an efficient pattern of emission reductions are based on the equalization between the marginal cost of reducing consumption to favor emission reductions and the marginal benefit of the lower risks to the climate that will be faced in the future (INPE, 2022).

Economic models from the cost-benefit analysis of climate change are based on standard models of the economic growth theory. In addition, the models used in empirical analyses seek to be simpler in order to be mathematically treatable (Boutabba, 2014). In these models, the objective is to maximize social welfare, which is the simple sum of the utility of all individuals, in all periods of time (a measure of income or consumption updated to the present value by a discount rate), on the basis of the projected climatic conditions (weighted by the probability of each one). For practical reasons, to achieve a complete analysis, we used one person to represent each region/country, along with the multiplier factor, which is the total population. Each model usually works for a few regions in the world (between 10 and 20). Representative individuals live for hundreds of years or even forever. Their well-being depends exclusively on their aggregate consumption of goods and services (Dietz & Maddison, 2009). The models then calculate investment patterns and emission growth that maximize the social welfare function. As such, the objective is to try to find patterns of investment and consumption that, considering present and future costs and benefits - updated to the present value by a discount rate - enable the greatest possible welfare for all individuals (INPE, 2022).

From the economic and social point of view, there is also inertia. As the maturation time of investments in infrastructure is usually decades, investments made condition the development of countries to carbon-intensive technologies. Investments in infrastructure and urban structures, for example, have medium-term impacts on emissions from the related sectors. This is the case for the construction of coal-fired power plants or transport systems (Dietz & Maddison, 2009; INPE, 2022).

By affecting the ecosystem services that are essential to human life and the economy, such as the regulation of hydrological flows and the rainfall regime, climate change can cause great economic damage; in particular, in infrastructure and agricultural activities. A rise in sea level by 1 meter by the end of this century would put at risk the lives of 60 million people and cause a loss of US$ 200 billion in assets in developing countries (World Bank, 2022). Even assuming an increase of only 2 °C, some estimates indicate that between 100 and 400 million people would go hungry (Easterling et al., 2007) and that 26% of people do not have access to enough water for their survival (International Panel Climate Change, 2019). On the one hand, the accumulation of GHG in the atmosphere is mainly related to the development process of the rich countries. Today, rich countries possess one-sixth of the world's population, but they account for two-thirds of current emissions (World Bank, 2022).

On the other hand, the majority of developing countries, which have contributed least to the increased concentration of these gases in the atmosphere, will suffer the worst damage. Some estimates suggest that developing countries should account for 75-80% of the costs of economic and social losses due to climate change (World Bank, 2020).This is due to several characteristics of developing countries, such as high economic dependence on ecosystem services due to the importance of agricultural and extractive production in their economy, populations concentrated in places most exposed to risks and vulnerable economic conditions, and low economic and institutional capacity to adapt. It is estimated that a rise in temperatures of 2 °C could lead to 4% to 5% losses in gross domestic product (GDP) in countries in Africa and South Asia, and only minimal losses in this indicator in rich countries, which leads to average global losses of 1% (Nordhaus, 2019) . Thus, the lack of an adequate response to the problem will deepen the social and economic gap between rich and poor countries (INPE, 2022).

3. Materials and Methods

The research method used in this study was statistical modeling, which is based on a study of multiple regression models of Brazilian industrial production, i.e., an analysis of the extent of economic, environmental and social phenomena in Brazil compared to the volume of greenhouse gases.

According to (Biembengut, 2014), modeling represents the process involved in developing a model of any area of knowledge. It emerges when there is a genuine doubt and/or circumstance instigating the need to find the best way to achieve a solution, find means to understand, troubleshoot, modify or even create or improve something. As such, the model is expressed through drawings or pictures, designs, layouts, graphics, mathematical laws, or other forms (Biembengut, 2014).

3.1 Data Collection

The implementation of this research took place in four stages.

In the first stage, the greenhouse gas emissions of Brazil was analysed. Data was obtained from the SEEG platform in 2023 for the year 2022, in order to understand the volume of Brazilian greenhouse gas emissions.

The data, displayed in Table 1, were collected according to the following pattern for the explanatory variables. Only the variables that both the literature and conventions have already empirically shown to have influenced the emission of greenhouse gases, regardless of the location, were considered. For this purpose, Table 1 shows the database.

Table 1a. Environmental factors

Factor	Symbol	Unit of measurement	Data Bank	Source
Carbon dioxide	CO_2	kt	(European Comission, 2023)	(Beach et al., 2015; Galbally et al., 2005)
Carbon dioxide per capita	CO_{2pc}	kt	(European Comission, 2023)	(Beach et al., 2015; Galbally et al., 2005)
Adjusted savings: Damage caused by particles	$NRB_{(DCP)}$	% (US Dollar)	(World Bank, 2022)	(Karavalakis et al., 2013)
Fossil fuel consumption	FC	kt	(IEA, 2022)	(Heede, 2014)
Total natural resources per income	$NR_{(total\ per\ income)}$	US Dollar	(World Bank, 2022)	(Ekins & Simon, 2004; Nocera, Tonin, & Cavallaro, 2015)
Forest area	FA	Km^2	(European Comission, 2023)	(DeFries et al., 2007; Miles & Kapos, 2008)
HFC, PFC and SF6	Other Gases (OG)	kt	(World Bank, 2022)	(Ranson & Stavins, 2016)
Methane	CH_4	kt	(World Bank, 2022)	(Knox et al., 2015; Philippe & Nicks, 2015)
Nitrous oxide	N_2O	kt	(World Bank, 2022)	(Philippe & Nicks, 2015; Voigt et al., 2017)
Gaseous CO_2	CO_{2g}	kt	(European Comission, 2023)	(Beach et al., 2015; Galbally et al., 2005)
Liquid CO_2	CO_{2l}	kt	(European Comission, 2023)	(Beach et al., 2015; Galbally et al., 2005)
Solid CO_2	CO_{2s}	kt	(European Comission, 2023)	(Beach et al., 2015; Galbally et al., 2005)

Table 1b. Economics factors

Factor	Symbol	Unit of measurement	Data bank	Source
Total reserves	TR	US Dollar	(World Bank, 2022)	(Psaraftis, 2012)
Gross domestic product	GDP	US Dollar	(World Bank, 2022)	(Bosetti, Carraro, Massetti, & Tavoni, 2008)
Gross domestic product per capita	GDP_{pc}	US Dollar	(World Bank, 2022)	(Peters & Hertwich, 2008)
Foreign investment	FI	US Dollar	(World Bank, 2022)	(Bosetti et al., 2008)
Gross domestic product	GDP_{ind}	US Dollar	(World Bank, 2022)	(Peters & Hertwich, 2008)
Gross domestic product growth	GDP_g	US Dollar	(World Bank, 2022)	(Peters & Hertwich, 2008)
Gross domestic product per employed person	GDP_{ep}	US Dollar	(World Bank, 2022)	(Bosetti et al., 2008)
Adjusted savings: damage caused by CO_2	$NRB_{(DCC)}$	% (US Dollar)	(World Bank, 2022)	(Nocera et al., 2015)

Table 1c. Social factors

Factor	Symbol	Unit of measurement	Data Bank	Source
Human development index	HDI	-	(UNDP, 2017)	(Natoli & Zuhair, 2011)
Workforce	WF	-	(F. O. Neves & Salgado, 2017)	(Lehmann, 2013)
Total population	TP	Millions	(UNDP, 2017)	(Jones & Kammen, 2014)
Population growth	PG	%	(UNDP, 2017)	(Jones & Kammen, 2014)
Agricultural lands	AL	Km^2	(FAO, 2022)	(Kraus et al., 2016)

In the third stage, the regression models were adjusted, relating the amount of greenhouse gas emissions and economic, environmental and social factors, according to current discussions in major sustainability reports such as the International Energy Agency, International Panel on Climate Change and COP 27. After obtaining the results, these were analysed to obtain the final results.

Finally, in the fourth stage, after selecting the factors through multiple regression models, the canonical correlation analysis (CCA) was developed to observe the behavior of the adjusted factors with the temperature variation during the studied period.

3.2 Modeling

In the construction of multiple regression models, it is necessary to select the independent variables that will be part of the model. In general, the problem is to properly select a set of variables that include variables that are considered important by the researcher (Hair-Júnior, 2009; Mann, 2006).

In order to identify the emission of greenhouse gases in Brazil, and the influence of environmental, economic and social factors on GHG in Brazil, the multiple regression models were adjusted.

According to (Draper, N R, Smith, 1998), a multiple regression model expresses a linear relationship, relative to the parameter, between a dependent variable (y) and two or more independent variables (x), where parameter β_0 is the linear coefficient or intersection of the hyperplane.

$$y= \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_p x_p + e \quad (1)$$

Parameter β_j, with j = 1, 2 ..., p, represents the expected variation in response y per unit of unit variation in x_j, when all other independent variables x_i $(i \neq j)$ are held constant; e is the independent random error, which has the assumption of following a normal distribution with a zero mean and constant variance.

The estimates of the parameters of the multiple linear regression models were performed using the least squares method (Hair-Júnior, 2009). The ANOVA was used to verify the significance of the multiple regression models. The value of this statistic (F-ANOVA) results from the relationship between the explained variance and the variance not explained by the model (Mann, 2006). Student's t-test was used to test the statistical significance of the estimated coefficients for each of the parameters and the hypothesis is that the estimated coefficient is either equal to or different to zero (Hair-Júnior, 2009; Mann, 2006).

3.2.1 Validation Test

For the validation of the multiple regression models, the following steps were followed in the waste analysis: Multicollinearity test whose purpose was to select variables and verify the quality of the model. Therefore, a correlation matrix was performed, first, in the phases of selection of environmental, social and economic variables. Selecting only the variables that presented non-significant linear correlation with each other, with $|r| < 0.5$, and this r assumes values between -1 and +1 ($-1 < r < 1$). In the adjustment of the final hybrid model, the same analysis was developed to verify multicollinearity, adjusting it, this time with the sum of the environmental, social and economic factors that were previously selected, again with $|r| < 0.5$, and then doing the inflation test (vif) to check if there was overfitting in the model (quality of the model), where ideal vif is ≤ 10 (F. de O. Neves, Salgado, Beijo, Lira, & Ribeiro, 2021). Other tests for validation of the adjusted model of the models were: ANOVA – for which significant models were accepted ($p < 0.05$) - and the lowest Akaike value (AIC) found in the different models studied (Neves et al., 2021, 2017).

3.2.2 Waste Analysis

a) Normality test – normality was verified via the Shapiro-Wilks test to see whether the waste had normal distribution (p-value SW);

b) Homoscedasticity test - via the BreuschPagan test, it was verified whether the waste was homoscedastic (p-value Bp);

c) Dependence test - via the Durbin-Watson test, the independence of the waste was verified (p-value DW).

A 5% significance level was used for all the tests (F. de O. Neves, Salgado, & Beijo, 2017).

3.3 Canonical Correlation Analysis

After developing a set of X variables that influence a Y set (temperature variations), the CCA was developed to analyze the strength of the sustainability indicators (Group X) on GHG emissions, in relation to the temperature variation set (Group Y), according to the steps of (Androniceanu, Georgescu, Tvaronavičiene, & Androniceanu, 2020).

For the CCA, the canonical pair ith was used (X_i, Y_i), being the correlation between groups X and groups Y, represented by Equation 2.

$$p_i^* = \frac{cov\ (X_i, Y_i)}{\sqrt{var\ (X_i) var\ (Y_i)}}, ith\ \ (X_i, Y_i) \tag{2}$$

The main objective of the CCA is to find the linear combination that maximizes the canonical correlation p_i^* for the canonical pairs in the ith group $ith\ \ (X_i, Y_i)$.

The following four steps were performed.

1) This is to determine whether there is a relationship between the two groups of variables. Via Wilks' lambda, we reject the null hypothesis that there is no relationship between the two sets and can conclude that they are dependent;

2) The null hypothesis in item *i* above is equivalent to the null hypothesis that all ith pairs of canonical variables are uncorrelated: $H_0 : p_1^* = \cdots = p_{ith}^* = 0$. Wilks' lambda is significant and the canonical correlations are in descending order, so we conclude that at least $p_1^* \neq 0$. Thus, it is verified the Pearson correlation coefficient that each variable of the group X_i correlates to the group of variables Y_i;

3) To interpret each canonical variable, we calculate the correlation between each variable and the corresponding canonical variable;

4) Finally, the best predictors were found for each variable in the dependent set, determining the correlations according to the scale by (Kvam & Kang, 2011), which is shown in Table 2:

Table 2. Intensity of correlations

Valuation of ρ	Intensity
0.0 - 0.19	Very Weak Correlation
0.2 - 0.39	Weak Correlation
0.4 - 0.69	Moderate Correlation
0.7 - 0.89	Strong Correlation
0.9 - 1.0	Very Strong Correlation

4. Results and Discussions

The emission of greenhouse gases in Brazil will be described, then the environmental, economic and social factors that influence its emission will be verified.

4.1 Emission of Greenhouse Gases in Brazil

The emission of greenhouse gases in Brazil is mainly concentrated in five sectors: land use change, residues, industrial processes, farming, land use change and forestry and energy, as shown in Figure 1.

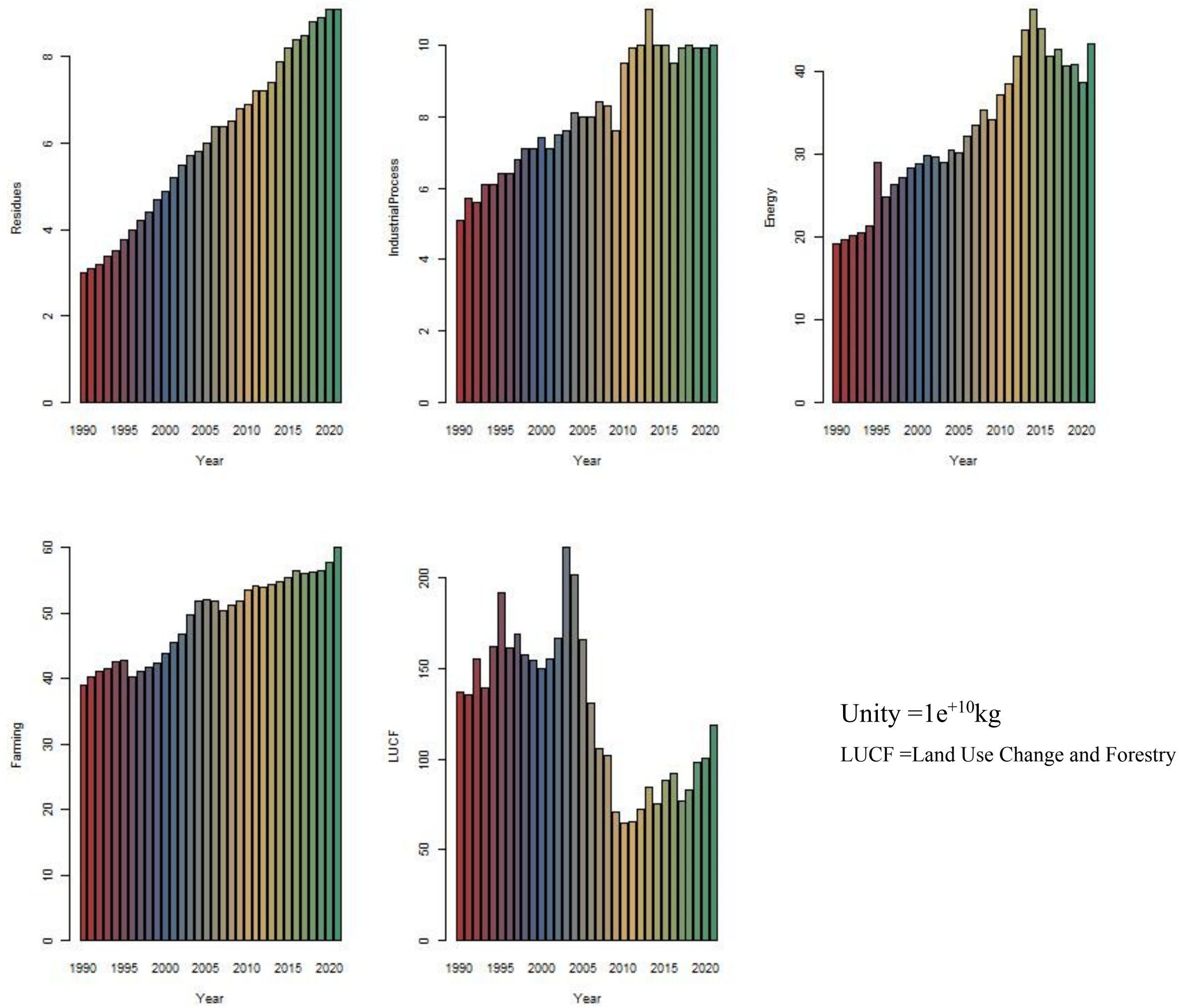

Figure 1. Cumulative values of the sectors that emit greenhouse gases in Brazil (Adapted from (SEEG, 2022)).

As of 2009, there have been drastic reductions in greenhouse gas (GHG) emissions in Brazil. A drop of more than 70% in the deforestation rates in the Amazon have helped Brazil to lower its share of global emissions from 6.2% in 2004 to 2.9% in 2012, putting Brazil in a good position to start discussions on the new global climate agreement that is in line with the Paris Agreement, which replaced the Kyoto Protocol in 2020. Compared to Brazil between 2004 and 2012, global emissions increased by 7%. However, the estimates generated by the Climate Observatory point to a clear trend of growth in GHG emissions from the energy, transport, agriculture and livestock, industry and solid waste sectors. The same trend that occurs in Brazil; though with the replacement of transport by land use change (SEEG, 2022).

When the emissions from land use change between 1990 and 2015 are excluded, there was only reduction in GHG emissions in Brazil in 2009, as a result of the global economic crisis, which started in the second half of 2008. In 2010, GHG emissions started to grow again, at a faster rate than in 2008, and followed this trend until 2015. The increasing deforestation of the Amazon rainforest, which for years was the main source of Brazilian emissions and accounted for about 70% of the total in the 1990s, dropped to 32% as of 2012 (SEEG, 2022).

4.2 Analysis of the Adjusted Multiple Regression Models

After describing the emission of greenhouse gases in Brazil, the environmental, economic and social factors that influence the emission of total greenhouse gases in Brazil were verified. First, the factors were selected and then, the adjustment of the multiple regression models was possible.

4.2.1 Multiple Regression Model Adjustment

After selecting the factors shown in Table 1, the multiple regression models, which are the main subject of study of this work, were adjusted. The sequence involved in order to achieve the models, from the selection of variables to their validation, is in the topic of Section 3.2.

Table 3 shows the adjusted multiple regression models for the selection of variables for the model considered in the analysis (hybrid). The methods for analysis and validation of the models presented in section 3.2 were followed for the adjustment of the models (the estimation of factor coefficients and their respective standard errors, SE (β) and the p-value of the Student-t statistic). Thus, it was possible to identify which variables affect greenhouse gases.

Table 3. Adjusted multiple regression models

Models	Variable	β	SE(β)	p-value
Economic	Interceptor	1.92_x10^{+06}	2.34_x10^{+05}	<0.0001
	GDP	4.719	1.031	0.0002
	GDPpc	-8.83_x10^{+08}	2.18_x10^{+08}	0.0005
Environmental	Interceptor	8.45_x10^{+07}	9.78_x10^{+06}	<0.0001
	FA	-1.19_x10^{+04}	1.44_x10^{+03}	<0.0001
	FC	-1.66_x10^{+08}	3.27_x10^{+07}	<0.0001
	N_2O	8.24_x10^{+04}	2.08E+04	0.0008
	CH_4	-6.66_x10^{+04}	1.22_x10^{+04}	<0.0001
	$NRB_{(DCC)}$	-6.57_x10^{+09}	1.31_x10^{+09}	<0.0001
Social	Interceptor	4.35_x10^{+06}	1.06_x10^{+07}	0.686
	HDI	-5.60_x10^{+05}	4.46_x10^{+04}	0.0009
	PG	-8.16_x10^{+10}	1.38_x10^{+09}	0.0006
	AL	-4.07_x10^{+04}	4.20_x10^{+03}	0.0009
Hybrid	Interceptor	4.66_x10^{+06}	5.39_x10^{+05}	<0.0001
	GDP	0.0044	0.07386	<0.0001
	FA	-3.85_x10^{+12}	1.74_x10^{+05}	0.0017
	CH_4	2.85_x10^{+01}	9.99_x10^{+06}	0.0094
	PG	2.82_x10^{+02}	1.89_x10^{+07}	0.0061

Table 4 shows the results of the validation tests for the multiple regression models, from the selection of variables by AIC, R^2_{aj} and the value of ANOVA (p-value) for the validation of the model through waste, homoscedasticity, normality and dependency tests. Note that compliance with the assumptions inherent to the multiple regression analysis was confirmed for all adjusted models: linear relation between the dependent variable and each of the independent variables; constant variance of the regression errors; independence of the waste; waste is normally distributed; and there is no strong multicollinearity among the independent variables.

Table 4. Validation tests of the multiple regression models

	p-value SW	p-value Bp	p-value DW	AIC	R^2	R^2_{Aj}	ANOVA (p-value)	vif
Economic	0.3348	0.6834	0.1236	754.093	0.934	0.9022	<0.0001	k = 8.2
Environmental	0.3169	0.4179	0.7979	743.1872	0.980	0.9612	<0.0001	k=6.7
Social	0.9569	0. 3355	0.5538	783.8257	0.88	0.8704	0.0001	k= 5.3
Hybrid	0.101	0.9623	0.6539	734.0433	0.9549	0.9272	<0.0001	K=7.4

The social model has a p-value that is greater than 0.05, so the intercepts do not fit in the model. The factors that were not selected and not adjusted in the hybrid multiple regression models are shown in Table 5. These factors were either rejected in the multicollinearity test or were not selected in the adjusted multiple regression models.

Table 5. Factors that did not enter into the selection of factors and the hybrid multiple regression models

Model	Factors
Economic	FI, TR, GDP_{ind}, GDPg, GDP_{pc}, GDP_{ep}, NR ($_{total\ per\ income}$)
Environmental	NO_2, CO_2, OG, CO_{2s}, CO_{2l}, CO_{2g}, CO_{2pc} and $NRB_{(DCP)}$
Social	WF and TP

Table 1 contains the meanings of the acronyms for Tables 3 and 5

4.3 Discussion of the Hybrid Adjusted Multiple Regression Model

In this section, an analysis is performed using the hybrid multiple regression model represented in Equation 3.2 of the adjusted data found in Section 3.2. Equation 3 aims to verify which social, environmental and economic factors influence the emission of greenhouse gases in Brazil.

$$GHG= 5.77_x10^{+05}+2.82_x\,10^{+2}PG +2.85_x10^{1}CH_4 + 4.4x10^{-03}GDP - 3.85_x10^{12}FA \quad (3)$$

According to the analysis of the model represented by Equation 3, it is noticed that it is influenced by four different explanatory variables: the gross domestic product (GDP), population growth (PG), methane (CH_4) and forest area (FA). In this way, according to Equation 2, by increasing the gross domestic product by 1 billion dollars, and keeping the other explanatory variables constant, the emission of gases that cause the greenhouse effect in Brazil will grow by 4.4_x10^{-03} ton per cubic meter (t/m^3.) For the environmental aspect, when increasing 1 ton of methane gas, keeping the variables gross domestic product and population growth constant, the emission of gases that cause the greenhouse effect will grow by 2.85_x10^1 t/m^3. By increasing the population in Brazil by 1 million, and keeping the other variables constant, the emission of gases that cause the greenhouse effect will decrease by 2.82_x10^{+2} t/m^3. And, finally, by leaving the variables gross domestic product, methane and population growth constant though increasing 1 km^2 of forest area, the emission of greenhouse gases will decrease by 3.85_x10^1 t/m^3.

According to data in Table 1, the Gross domestic product is the sum of goods and installment of remunerated resources. Therefore, it can be said that the gross domestic product influences the emission of greenhouse gases because it is responsible for the sum of all industrial production, whether through tangible or intangible products. The GDP needs a gigantic infrastructure for its production system, from logistics, production and consequent disposal of waste emissions, to the disposal of some products that can increase the generation of greenhouse gases, which justifies this action (F. O. Neves & Salgado, 2017).

Moreover, it is important to point out that Brazil currently occupies the 9^{th} place in the ranks of the world's economies and is the 13^{th} country in terms of volume of industrial production, as can be observed in Figure 2.

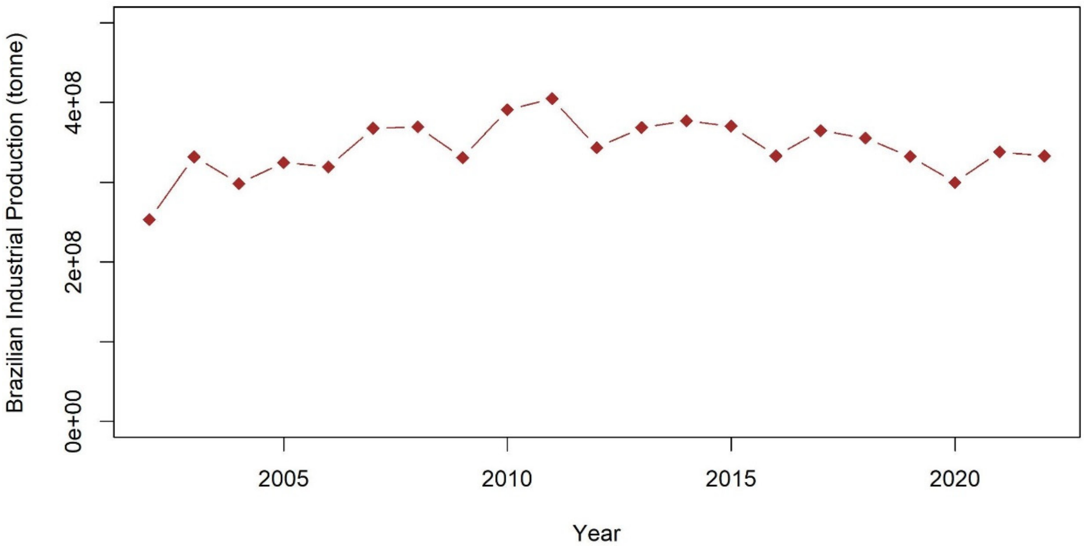

Figure 2. Volume of Brazilian industrial production between 1990 and 2022

Although there are some tools, control agencies and even legislation, in the attempt to mitigate the emission of greenhouse gases, this problem has not yet been resolved.

In addition, the public and private investment in renewable energies is necessary so that a reduction in GHG emissions occurs. According to Garcia-Heller et al. (2016), Brazil has great potential in this regard, but it is not explored appropriately. The high cost of this technology and the lack of interest on the part of some companies, because oil is still economically viable, tend to slow the growth of consumption of renewable sources of energy.

Regarding the environmental methane factor (CH_4), it is one that positively influences the emission of greenhouse gases in Brazil. Gas of natural and anthropogenic origin in Brazil, as reported in the (International Panel Climate Change, 2019), originates from livestock farming. In addition, most of the studies in the area (Carvalho et al., 2014; Latawiec et al., 2017; Siqueira & Duru, 2016) report that the greater emission of gases is linked to the improvements in cattle diet, to the improvement of pastures and other measures that reflect in more efficient production, improving digestibility and consequently, bringing about shorter cycles of bovine production. Measures that minimize methane gas production from ruminant digestion processes, as occurs with crop-livestock-forest integration (CLFI – crop-livestock-forest integration) through integrated systems, retain more carbon and improve digestion of methane emissions by ruminants. Since the system decreases the amount of fibrous fodder, it thus increases the nutritional potential of the feed and therefore helps to decrease methane production and retain more carbon. However, in areas of degraded pasture, as in some regions of northern Brazil, soil conditions cause an increase in the loss of organic matter and the soil releases large amounts of CO_2 and CH_4 into the atmosphere (Ribeiro et al., 2021).

Thus, it is necessary to observe the dynamics of greenhouse gases holistically. All the compartments of the productive systems must be taken into account: soil, plant, animal and the atmosphere, since some components can carry out the removal of GHG, thus reducing emissions (Wu & Mu, 2019).

Another factor that has influenced the emission of greenhouse gases in Brazil is population growth. According to(Stern, 2017), as the population grows by 1%, the growth in greenhouse gas emissions also follows the 1% growth. In Brazil, the emission of greenhouse gases for this factor is related to sectors that generate human consumption. In 2022, energy consumption for the transport and industrial sectors were respectively 32.2% and 32.1% (EPE, 2021), primarily in urban centers, the place of greatest population growth. Thus, as shown in Figure 2, the volume of industrial production in Brazil has remained constant over the years, despite fluctuations, the same phenomenon occurs with the transport sector, which has the characteristic of being concentrated in specific large urban centers in the southern and southeastern region of Brazil (Brazilian Institute of Geography and Statisticsa, 2023) and, specifically in this geographic sphere (higher population concentration), the emission of greenhouse gases has these characteristics.

Finally, the FA indicator shows that each time the forest area decreases, there is a significant increase in the emission of gases that cause the greenhouse effect. In the year 2022, according to SEEG (2023), there was an increase of approximately 10% in greenhouse gas emissions. In particular, in the last four years, the increase in GHG emissions increased by 419742605 tons from the forest area, however, there was a decrease in approximately 11,000km^2 of the same area.

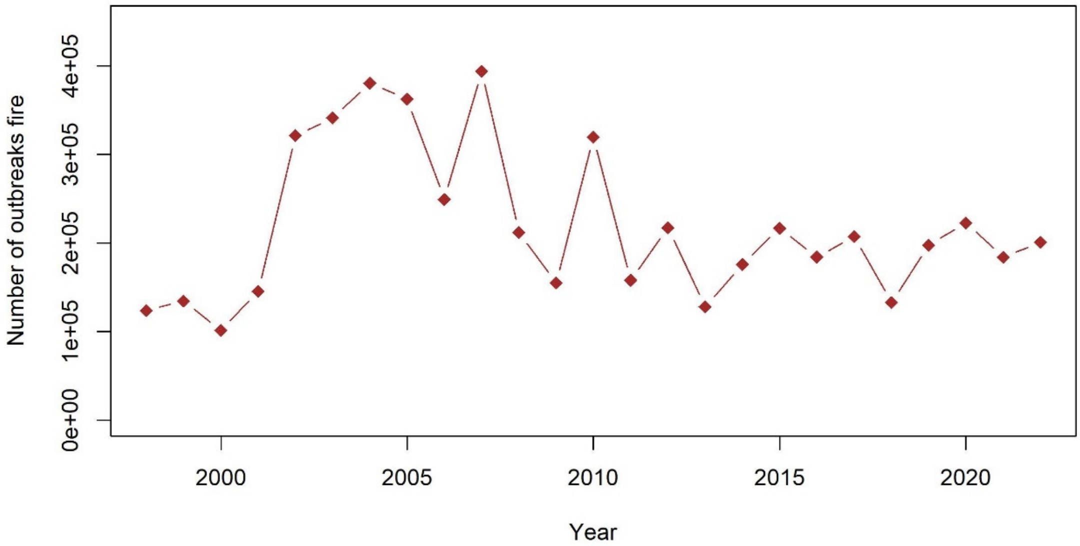

Figure 3. Number of outbreaks of fire in Brazil from 1998-2022

The excessive emission of gases that make up the greenhouse effect implies the occurrence of the greatest increase in terrestrial temperature. With this, as highlighted in Section 3.3, we analyzed how these indicators would behave in the annual temperature increase, and in the variations after this period, such as 1 year, 2 years, 5 years, 10 years, 15 years and 22 years after (Table 6). Thus, there is a general diagnosis of how the behavior of these factors goes beyond the action on the emission of gases that increase the greenhouse effect.

Table 6. Relationship between adjusted indicators and variations in temperature in Brazil

	ΔT	ΔT_1	ΔT_2	ΔT_5	ΔT_{10}	AT_{15}	AT_{22}
GDP	0.98	0.32	0.20	0.21	0.27	0.23	0.25
CH4	0.23	0.4	0.81	0.50	0.15	0.12	0.08
PG	0.95	0.88	0.76	0.20	0.09	0.09	0.07
FA	0.18	0.17	0.56	0.68	0.89	0.92	0.98

ΔT= year; $\Delta T_{1=}$ 1-year variation, $\Delta T_{2=}$ 2-year variation, $\Delta T_{3=}$ 3-year variation; $\Delta T_{5=}$ 5-year variation, $\Delta T_{10=}$ 10-year variation, $\Delta T_{15=}$ 15-year variation, $\Delta T_{22=}$ 22-year variation.

Table 6 portrays the intensity of the relationship of the factors that were adjusted, through Equation 2, with the correlation of variation in temperature in Brazil during the last 22 years, considering the strength of the determination coefficient indicated in Table 2.

The GDP indicator is very strongly correlated with temperature in the same year that it has an increase. The constitution of the Brazilian GDP is basically made up of commodities and industrial production. Commodities are added to monoculture for export and extensive livestock farming. In Brazil, these two factors which make up the GDP and have a high correlation with the temperature variations in the years, are cultivated in a region with a high density of native biomes, in which the expansion of this type of crop is characterized by the felling and burning of trees in these biomes (F. O. Neves & Salgado, 2017). Additionally, in Table 6, it is observed that, after ΔT, the temperatures have a low correlation, as the environments are conditioned with this expansion. In industrial production in Brazil, in the last 10 years, there was a smaller variation than in 2011, even so, it is of great importance with the increase in temperature mainly in urban areas through the excessive consumption of non-renewable energy from fossil fuels, forming the so-called smog (F. Liu, Chang-Richards, Wang, & Dirks, 2023).

The methane indicator, after a period of 2 years, showed a strong coefficient of determination (0.81), as a result of the bovine pasture that, from two years onwards, has a plant physiological structure that is suitable for bovine consumption. Cattle emit excessive CH_4 through the digestion process from rumination and, as the methane molecule has an ability to absorb heat that is approximately 24 times greater than that of CO_2, there will be a greater possibility of extreme weather as a result of methane emissions (Króliczewska, Pecka-Kiełb, & Bujok, 2023; Palangi, Taghizadeh, Abachi, & Lackner, 2022). Like CH_4 and GDP, the FA indicator has a great relationship with deforestation in Brazil, because, as indicated by Equation 3, the smaller the forest area, the greater the increase in greenhouse gases. Also considering Table 6, after ΔT_2, a constant increase in the correlation of temperature variation in Brazil with the FA factor begins, and within this sample space, when arriving at ΔT_{22}, it will show its peak correlation. As already highlighted by the (International Panel on Climate Change, 2023) and (United Nations Climate Change, 2022) , the maintenance of native biomes has the aim of adjusting the terrestrial temperature to pre-industrial levels, so that there is no extinction of animal and plant species, as already observed with the extinction of certain animals in the class of amphibians. Still, whenever there is a great demand for products of industrial and monoculture origin, there is a movement in these indicators (F. O. Neves & Salgado, 2017).

The population growth (PG) indicator, on the other hand, greatly influences the year of its immediate increase, in addition to when there are 1 and 2 years of variations. This rapid impact is related to the growth of the gross domestic product and production for the consumption of tangible goods, because the great increase in the birth rate effectively causes a need to be supplied with the food and materials necessary for the survival of the young (Esfandeh, Danehkar, Salmanmahiny, Sadeghi, & Marcu, 2022). In this way, indicators such as origin in monoculture (GDP, CH_4 and FA) are indirectly altered.

5. Sustainable Political Implications

Brazil is one of the main emitters of GHGs in the world. Although, European countries, the USA and China have an emission rate through fuels of non-renewable origin, Brazil's emissions are mostly due to its characteristic production of commodities, mainly through livestock farming via methane emissions, as shown in Table 6 and Equation 3.

The indicators shown in Equation 3 confirm what is being discussed multilaterally by the main groups, such as the International Panel on Climate Change and COP 27, in order to combat the emission of greenhouse gases. In recent years, the country's gross domestic product has come about through a type of product (monoculture) that advances on the biomes in the central-west and northern region, the main area of Brazilian native forest. As the soil of this region, mainly the one that covers the north of the cental-west and the northern region of Brazil, has sandy characteristics (Da Silva et al., 2022). Monoculture and livestock farming, when production does not involve large numbers, migrate to other places in the native forest (Mansoor et al., 2022). Unfortunately, the forecast is that the tipping point will be in 2030 or so. In this way, the characteristics of non-sustainable extractive monoculture make it difficult to reduce GHG emissions, especially with the advance of farming frontiers into the Amazon Forest(Boulton, Lenton, & Boers, 2022; Lapola et al., 2023).

As a result, the four adjusted indicators (GDP, CH_4, FA and PG) can help public decision-makers to gain a more comprehensive view of both the temperature changes and extreme weather events that have been occurring in Brazil and in the surrounding countries in recent years. In relation to seasonal diseases, yellow fever and dengue increase mainly with the advance of the clearing of native areas and with the increase in the terrestrial temperature. As can be seen from Table 6, it takes a period of 10 years for temperatures to increase, and the disease vectors are already adapted to the new location and, thus, the endemics become more and more common (Guégan et al., 2023; Hagen et al., 2022).

6. Conclusions and Future Perspectives

This paper provides an analysis of the profile of greenhouse gas emissions in Brazil, with data on emissions during the period 1990-2022. The main contribution of this study was twofold: to verify which sectors according to Brazil's national data are the ones that emit the most greenhouse gases, and to observe through the tests of adjustment of multiple regression models which social, economic and environmental factors influence the emission of GHG in Brazil and how they behave according to the variations in temperatures in Brazil that occurred during the study period.

The main conclusions can be summarized as follows. The data indicate that in the period of study the major sectors that influence the greenhouse effect were changes in land use, farming, energy, industrial processes and residues.

In the adjustment of the multiple regression model of 25 factors, only 4 were adjusted in the hybrid multiple regression model, namely, gross domestic product, forest area, methane and population growth. The decrease in forest area leads to an increase in GHG emissions, while the other 3 factors (GDP, CH_4 and PG) increase the emission of greenhouse gases in Brazil. It can be observed that GDP and PG have a high correlation in the same year that there is an increase, while CH_4 correlates after the temperature variation of 2 years and FA after 10 years.

Furthermore, regarding the influence of methane and gross domestic product and forest area on the emission of greenhouse gases, it can be concluded that the diffusion is a result of the extensive agricultural production system, burning and holistic systems (CH_4). The population growth indicator is related to the increase in extensive food production and industrial production to meet basic needs.

In summary, the main contributions of the paper can be summarized as follows: first, development of a diagnosis of the behavior of sustainability indicators that influence the emission of greenhouse gases in Brazil and how they behave with the increase in temperature. Provide contributions that support the decision-making of government agencies through the statistical analysis methods developed herein.

Another central point is the analysis of the sustainability assessment of GHG emissions and temperature variation in a developing country in which the economic demands are essentially agricultural commodities and industrial production of reproductive manufacturing, in adaptability to sustainability. Public policy makers can employ this study in possible adaptations in this sector in order to improve the reduction in greenhouse gas emissions.

However, the study points out some limitations in its development, such as a greater coverage of data in the last four years, mainly in the period of the COVID-19 pandemic. As such, there is a need to extend the development of models to the Brazilian regions and countries that border biomes so that it is possible to get a systemic view of the general behavior of this region and have a structured view of all sectors that make up the Brazilian economy, with its relation to GHG emissions and temperature variations, by developing the same methodologies set out in this work.

As an academic contribution, this article provides new concepts and guidelines on the analysis of greenhouse gas emissions and the correlation of temperature variations in Brazil, and is thus an advance in research involving environmental sciences. As for the governmental sector, it can be used as a parameter to help reduce greenhouse gas emissions and stanch the temperature in Brazil.

Based on these suggestions, future studies may emerge from this article. Further research is needed to verify, through several multinomial regression models, the tendency presented by the factors of this study. Checking in the future if these factors continue to influence GHG emissions, or if other factors are adjusted in the new multiple regression models.

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