Greenhouse Gas Emissions from Brazilian Agriculture

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ABSTRACT

This work aims to assess whether there is a convergence in the emission of Greenhouse Gases (GHG) in the states of Brazil. To achieve this objective, the Phillips and Sul (2007) time series methodology was employed, testing the hypothesis of global (or common) convergence, using data from the Greenhouse Gas Emissions and Removal Estimation System (*Sistema de Estimativas de Emissões e Remoções de Gases do Efeito Estufa* - SEEG), for the period of 1989-2018, which provides the emission, in tons, of Carbon Monoxide (CO) in agriculture and livestock, as well as of Carbon Dioxide (CO2), for changes in land and forest use. Among the main results, the formation of different convergence clubs is suggested, rejecting the hypothesis of global convergence, and thus presenting four convergence clubs for the CO pollutant and three clubs for the CO2, with two divergent states. When analyzing the convergence clubs, it was found that there was a significant reduction in CO emissions in all clubs, and while analyzing the CO2, only two of the clubs, which were clubs 3 and 4, managed to reduce their emissions.
Key-Words: Greenhouse Gases, Convergence Clubs, Time Series.

RESUMO

Este trabalho tem como objetivo avaliar se há convergência na emissão de Gases de Efeito Estufa (GEE) nos estados do Brasil. Para atingir esse objetivo, foi empregada a metodologia de séries temporais de Phillips e Sul (2007), testando a hipótese de convergência global (ou comum), utilizando dados do Sistema de Estimativas de Emissões e Remoções de Gases do Efeito Estufa - SEEG), para o período de 1989-2018, que prevê a emissão, em toneladas, de Monóxido de Carbono (CO) na agricultura e pecuária, bem como de Dióxido de Carbono (CO2), por alterações em solos e florestas usar. Entre os principais resultados, sugere-se a formação de diferentes clubes de convergência, rejeitando a hipótese de convergência global, apresentando assim quatro clubes de convergência para o poluente CO e três clubes para o CO2, com dois estados divergentes. Ao analisar os clubes de convergência, verificou-se que houve redução significativa nas emissões de CO em todos os clubes, e ao analisar o CO2, apenas dois dos clubes, que eram os clubes 3 e 4, conseguiram reduzir suas emissões.
Palavras-chave: Gases de Efeito Estufa, Clubes de Convergência, Séries Temporais.

Área de Submissão: Meio ambiente, recursos naturais e sustentabilidade.
Classificação JEL: C32; Q54; Q56

1. Introduction

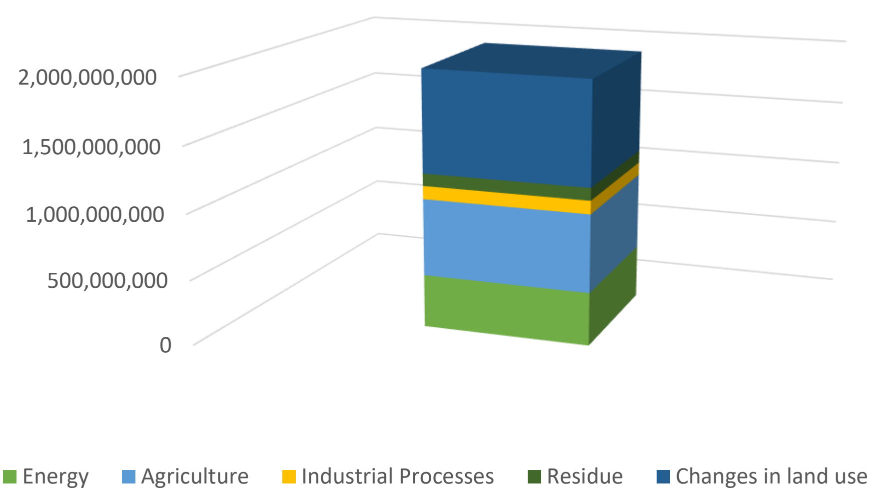
Climate change is one of the biggest challenges to be faced by society in the 21st century. This is a global issue, strongly related to the higher concentration of greenhouse gases (GHG) in the atmosphere, bringing risks to the balance of natural ecosystems and threatening the continuity of human life (LI et al., 2020).

A major milestone of the actions in favor of the reduction of global warming with worldwide adhesion was the Kyoto protocol (1997), where goals were set to reduce the GHG emissions that came into effect in 2005 (MOREIRA; GIOMETTI, 2008). Since then, internal actions to mitigate the climatic damage of human activities have been developed in Brazil, such as the National Plan on Climate Change (*Plano Nacional sobre Mudanças Climáticas* - PNMC).

In the midst of the PNMC, the Low Carbon Agriculture Plan (*Agricultura de Baixo Carbono* – ABC) was launched in 2012, a sectoral policy committed to mitigating GHG emissions by agricultural activities, encouraging the adoption of sustainable production technologies (GURGEL; LAURENZANA, 2016). The need to elaborate a specific plan for agriculture in Brazil occurs for several reasons, among which one can highlight the economic importance of the sector in the national economy.

In this context, agriculture has been identified as one of the main sector which are accountable for climate change (MARTINS et al., 2010), being responsible for 25% of the total GHG emissions in Brazil in 2018, thus occupying the second place among the sectors with the highest volume of emissions (ANGELO; RITTL, 2019).

Graph 1: GHG Emissions in 2018 by sectors



Source: Prepared by the authors.

Thus, compliance with the goals of mitigating environmental damage caused by agriculture is of significant importance, as this is a strategic sector for the national economy and of paramount importance in a scenario of increasing world population and a consequent increase in demand for food. In addition, agriculture is a sector that is very sensitive to changes in temperature and rainfall (MARTINS et al., 2010), which reinforces the urgency for actions to curb ongoing climate change.

Given the importance of meeting emission mitigation goals, it is advisable to comprehend the behavior of GHG emission levels in the Brazilian agricultural sector, so that public authorities can, based on this knowledge, review or develop new strategies to reduce emissions from GHG, and thereby reduce global warming. It is, then, necessary to analyze the behavior of GHG emissions in the federal units in Brazil. Do all Brazilian states have the same behavior, over time, of GHG emission levels? Are there clubs from federative units with different levels of GHG emissions? One way of verifying this behavior is using the methodology of convergence and convergence clubs (SOLOW, 1956; PHILLIPS and SUL, 2007).

In this sense, this work aims to analyze the behavior of GHG emissions from agricultural activities and changes in land use in the Brazilian states. More specifically, this research tests the hypothesis of convergence and / or formation of convergence clubs for these state emissions, from the aforementioned activities, in the period from 1989 to 2018.

This work contributes to the literature evaluating the convergence in eco-efficiency in GHG emissions among the Brazilian states using the Phillips and Sul (2007) approach, which tests the existence of convergence groups that share common characteristics in terms of eco-efficiency, that is, federative units that are at similar levels of production combined with environmental preservation, are stimulated by state incentives, pressure from buyers or acquired through the adoption of new technologies.

This methodology is especially suitable for this type of variable, where the concept of absolute convergence and stochastic and / or deterministic convergence can be very demanding. On the other hand, the test for convergence clubs can be a more flexible approach, as the clubs correspond to different levels of state achievement of eco-efficiency.

This study differs from others already carried out (for example, Haider and Akram, 2019; Akram, Sahoo & Rath, 2020), because, in addition to using another geographic area (in this case, Brazil), it uses information on CO and CO2 emissions for each federation unit of Brazil, or state, with data spanning three decades.

In addition, convergence clubs can be useful for examining eco-efficiency in a specific state in relation to other states. These groups help to identify similarities and differences among Brazilian regions, in addition to helping researchers and policy makers to develop generalized hypotheses.

This work is organized as follows. Section 2 is dedicated to a brief review of the literature that will serve as a basis for further discussion; Section 3 covers the database and methodology used. The results are presented and discussed in section 4. A final section is used to present the concluding remarks.

2. Literature Review

The convergence of GHG emissions among countries, regions or other space divisions has important implications for mitigating climate change. It provides a vision for policy makers and programs to design strategies to reduce environmental damage caused by economic activities (HAIDER and AKRAM, 2019).

The initial works on convergence were based on the neoclassical model (SOLOW, 1956), which hypothesizes that differences in income *per capita* among countries would decrease over time, converging to the same steady state level of equilibrium (SOFI; DURAI, 2016). Another aspect of the literature suggests that, instead of a stable global equilibrium, several locally stable equilibria may arise as a result of a dynamic system, that is, a convergence in clubs (BILGILI; ULUCAK, 2018; KING; RAMLOGAN-DOBSON, 2016).

The theme of convergence occupies a prominent place in the economic literature, as it discusses whether economies tend to converge in the same direction (in terms of output or per capita income). The work of Galor (1996) clarifies that there are three distinct convergence hypotheses, being:

a) Global or unconditional convergence: any two economies will tend to the same average level of per capita income in the long run (steady state), regardless of their initial conditions.

b) Conditional convergence: two economies with common structural characteristics (same preferences, technologies, population growth rates, public policies, etc.) will tend to the same average level of per capita income in the long run, regardless of their initial conditions.

c) Club convergence: any two economies that share the same structural characteristics and that have similar initial conditions will tend to have the same average level of per capita income in the long run.

This debate began in the 1980s, started by the work of Romer (1986), where the author discusses the theory of endogenous growth, and analyzes whether there is a general tendency for poor countries to catch up with rich countries.

Absolute or unconditional convergence assumes the same growth dynamics for all states (Islam et al., 2003). Unlike the unconditional convergence, the steady-state characteristics of the individual states imply conditional convergence, where each state has a particular steady-state equilibrium, where each UF approaches its own equilibrium in this concept. Likewise, if economies are grouped by common characteristics, each group has the same steady-state equilibrium and each group achieves its own equilibrium (Durlauf & Johnsan, 1995; Galor, 1996). This is known as club convergence.

Research that take into account the existence of multiple equilibria, or convergence clubs, are present in several works. Durlauf and Johnson (1995), using the regression tree method, verified and confirmed the hypothesis of convergence clubs for the product *per capita* of a group of countries. In Brazil, analyzes of convergence clubs were used to investigate various issues, such as the distribution of human development indicators in Brazilian municipalities (MAGALHÃES; MIRANDA, 2009), the evolution of the income distribution of states and / or municipalities in the country (GONDIM; BARRETO; CARVALHO, 2007; RIBEIRO; DE ALMEIDA, 2012), to analyze the income *per capita* of agriculture among the states (PENNA et al., 2012), the level of well-being (PENNA et al., 2013), and the convergence of agricultural markets (TABOSA; IRFFI; PENNA, 2015).

The definition of convergence is also applied in agriculture, where it seeks to analyze the development of the agricultural sector in a country or region, in a similar way to the analysis of an entire economy. Instead of analyzing whether economies converge in one direction, it investigates whether the output or income of agriculture has a tendency to converge, isolating this sector from the others.

Several authors have studied convergence in agriculture, for example, Yuan et al. (2021), which discusses whether world agricultural convergence has occurred. The authors use a model averaging method to consider both a parametric and a semi-parametric stochastic frontier model to better estimate technical efficiency. However, the empirical results on a balanced panel of 126 countries from 1970–2014 show that world agricultural convergence has not occurred.

In a previous work, Barrios (2007) proposes an agricultural convergence model, using both random effect and a spatial-temporal model for GDP convergence, for 28 Asian countries, where the author finds evidence of conditional convergence in some countries of the region, specifically, according to the results, conditioning on current trade, foreign aid (intended for agriculture), and public expenditures (for agriculture), Asian economies will converge in agricultural growth at the rate of approximately 15% per year.

Although the initial research on convergence aimed to study the relationship between the level of income *per capita* and the economic growth of nations, the levels of GHG emissions is another indicator of well-being (environmental well-being) that can be correlated with economic growth (EZCURRA, 2007). In this perspective, the development level would be assessed based on the eco-efficiency of each country. The term “eco-efficiency” refers to producing more goods and services with less environmental impact (CAMARERO, 2014).

As well as analyzes of income convergence, works that focus on studying the convergence dynamics of polluting gases incorporate the perspective of club formation, based on the same idea that there can be multiple equilibriums in the steady state. Based on this idea, Herreiras (2013) tests and confirms the hypothesis of convergence clubs for carbon dioxide emissions for a group of developed and developing countries between 1980 and 2009. With a focus on a specific sector, Liu et al. (2018), investigate the formation of convergence clubs in pollutant emissions from industrial activities in 285 Chinese cities.

Focusing on a perspective more aligned with the objectives of this research, it is possible to point out some analyzes of convergence clubs that were used in works related to the levels of GHG emissions.

Camarero et al. (2014), for instance, used the methodology of Phillips and Sul (2007) to test the existence of convergence clubs in eco-efficiency in GHG emissions among EU countries. The authors raised the hypothesis that, although there are common objectives and policies in the EU with respect to emission reduction targets, the differing levels of development, structural differences in economic activities, among other factors, may contribute to different equilibria, instead of only one. The hypothesis was confirmed, and the results suggest the existence of different convergence clubs, with one group strongly influenced by the degree of development of the countries.

Morales-Lage et al. (2019), in another application of the Phillips and Sul (2007) methodology for the EU, investigate the sectoral convergence in CO2 emissions between the years 1972 to 2012, showing the formation of convergence clubs in the energy sector, pointed out as a crucial sector regarding GHG emissions.

Considerations about the existence of convergence in clubs to evaluate environmental indicators is used by several other authors, whether to reveal the dissimilarities of participation among the main countries in CO2 emissions in climate change policy (HAIDER; AKRAM, 2019), indicate the progress of the G20 environmental policies (BILGILI; ULUCAK, 2018), to assess the OECD's more or less “eco-efficient” clubs (CAMARERO et al., 2013), among other works.

In terms of works which concentrate on one country, the work of Du et al. (2018), for example, analyzes the dynamics of convergence and the spatial distribution of convergence clubs in the carbon intensity of Chinese provinces in civil construction from 2005 to 2014, using the classical Markov chain and the spatial Markov chain methods. The results suggest the formation of convergence clubs. This characterization is influenced both by the local characteristics and the effects of the neighboring provinces, as well as the regional antecedents of development.

From a provincial perspective, a group with higher carbon intensity included Inner Mongolia, Xinjiang, and Shanxi.The provinces with an upward transition for carbon intensity were Xinjiang, Heilongjiang, Ningxia, Shaanxi, Anhui and Tianjin, which are located in the Northwest and North China. The provinces with a downward transition for carbon intensity were Liaoning, Jilin, Jiangxi, Guangxi and Hebei, which are clustered in the Northeast and South China on the whole. The results reveal that there are remarkable spatial clustering and regional convergence characteristics in China’s provincial carbon intensity (DU ET AL., 2018).

Furthermore, the research concludes that carbon intensity class transitions in China’s construction industry does not seem to exist in isolation and shows significant spatial dependence. The carbon intensity class transitions of regions mostly tend to be consistent with class transitions of their neighbors. According to Du et al. (2018), this spatial aspect may promote the spatial agglomeration and regional convergence of provincial carbon intensity.

Brazil is marked by inequality and this irregular distribution of its resources in the national territory covers the most diverse segments, such as income, access to education, infrastructure, technology. Therefore, the convergence among states with similar conditions can be better characterized by the club convergence approach, and this can serve as a basis for a more adequate focus on policies and programs aimed at reducing GHG emissions in the country, and different measures can be developed to the clubs formed by the states.

Oliveira Júnior, Castelar and Ferreira (2009) analyze the process of agricultural convergence in the microregions of Brazil, based on the value of agricultural production per capita in these locations. The authors identified the existence of 3 clubs, one formed by the poorest micro-regions, a second formed by the richest micro-regions, and a third by the intermediate ones.

3. Methodology

3.1 Data

In this work, a data set from the 27 federative units of Brazil was used. (, *i.e.* 26 states and the Federal District) covering the 1989-2018 period[i]. Thus, these federative units are: Acre (AC), Alagoas (AL), Amapá (AP), Amazonas (AM), Bahia (BA), Ceará (CE), Distrito Federal (DF), Espirito Santos (ES), Goiás (GO), Maranhão (MA), Mato Grosso (MT), Mato Grosso do Sul (MS), Minas Gerais (MG), Pará (PA), Paraíba (PB), Paraná (PR), Pernambuco (PE), Piauí (PI), Rio de Janeiro (RJ), Rio Grande do Norte (RN), Rio Grande do Sul (RS), Rondônia (RO), Roraima (RR), Santa Catarina (SC), São Paulo (SP), Sergipe (SE) and Tocantins (TO).

The GHG data used in this research originate from the Greenhouse Gas Emission Estimation System (*Sistema de Estimativas de Emissão de Gases de Efeito Estufa* - SEEG), launched in November 2019 during the Brazilian Climate Change Conference. Although SEEG estimates include sources of emissions from all sectors, the ones used in this work are the Agriculture and Changes in Land Use sectors, which include, respectively, Carbon Monoxide (CO) and Carbon Dioxide (CO2) emissions (AZEVEDO et al., 2018).

Regarding the CO emitted by the Agriculture sector, it originates from the burning of agricultural waste in the combustion phase. Throughout Brazil, the use of fire occurs mainly in sugar cane fields, while the burning of cotton waste is no longer a common practice in the mid-1990s (MCTI, 2015d). CO2 in agricultural soils, here treated as Changes in Land and Forest Use, results predominantly from its condition and management. Soils cultivated under conventional planting and degraded pastures tend to emit CO2 into the atmosphere due to the marked decomposition of the soil's organic matter. Thus, the minimum soil preparation can contribute to reducing the CO2 emission from the soil into the atmosphere (LAL, 2009).

The convergence test based on the regression developed by Phillips and Sul (2007) is discussed next, initially presenting the log *t* test. The test is based on the rate of cross-variation of the emission of gases over time. The unique characteristic of this methodology is the non-requirement for cointegrated time series, thus allowing individual behavior to be transitionally divergent[ii]. The method allows to endogenously reveal a wide spectrum of transition behavior among the Brazilian states, such as convergence to a common steady state, divergence and the convergence in clubs.

3.2 The *log t* test

The application of the *log t* test developed by Phillips and Sul (2007), allows to analyze the transition behavior of the emission of toxic gases between the Federative Units of Brazil in the period 1989-2018[iii]. The gases are measured in tons of carbon monoxide and carbon dioxide, respectively from the agriculture and livestock sectors, and changes in land and forest use. It should be noted that, before applying the test, the data were filtered to remove the business cycle using the Hodrick-Prescott smoothing filter (Hodrick and Prescott, 1997), as suggested by Phillips and Sul (2007). Typically, panel data is portrayed as:

$$logy_{it} = \varphi_i \mu_t + \varepsilon_{it} \tag{1}$$

Where φ_i represents the characteristic component unit, μ_t is the common factor and ε_{it} is the error term. Furthermore, the amount in tons of toxic gas emissions, $logy_{it}$ has a variable time representation factor that can be derived from conventional panel data representation, like this:

$$logy_{it} = \left(\varphi_i + \frac{\varepsilon_{it}}{\mu_t}\right)\mu_t = \delta_{it}\mu_t \tag{2}$$

Where δ_{it} absorbs the error term and the specific component of the unit, thus representing the idiosyncratic part that varies over time. This second approach aims to describe the amount of toxic gas emissions measured from δ_{it} the common growth trajectory μ_t which state *i* suffers. In order to model the δ transition coefficients, a relative transition coefficient,h_{it}, is constructed:

$$h_{it} = \frac{logy_{it}}{N^{-1}\sum_{i=1}^{N} logy_{it}} = \frac{\delta_{it}}{N^{-1}\sum_{i=1}^{N} \delta_{it}} \tag{3}$$

Thus, h_{it} represents the transition path of gas emissions of state i in relation to the average of the cross section, having a double interpretation: first, it measures the individual behavior in relation to other states, and second, it describes the relative outputs of state *i* of the common trajectory μ_t. In the case of convergence, that is, when the emission of toxic gases from all federative units moves to the same transition path, $h_{it} \to 1$ for all the i with $t \to \infty$. So, the transversal variation of h_{it}, denoted by $V_t^2 = N^{-1}\sum_i (h_{it} - 1)^2$, converges to zero. In the existence of non-convergence, there are several possible results. For example, V_t it may converge to a positive number, typical of convergence clubs, or remain bounded above zero and not converge or diverge.

In order to specify the null convergence hypothesis, Phillips and Sul (2007) models δ_{it} in a semi-parametric way:

$$\delta_{it} = \delta_i + \frac{\sigma_i \xi_{it}}{L(t)t^{\alpha}} \tag{4}$$

in which δ_i is fixed, σ_i is an idiosyncratic scalar parameter, ξ_{it} is iid(0,1), $L(t)$ is a slow-varying function (such that$L(t) \to \infty$ when $t \to \infty$) and α is the rate of decay[iv]. The null and alternative hypothesis of convergence can be written as:

$$\begin{aligned} &H_0: \delta_i = \delta \text{ e } \alpha \geq 0 \\ &H_A: \delta_i \neq \delta \text{ e } \alpha < 0 \end{aligned} \tag{5}$$

In the null hypothesis of convergence, several transition patterns of gas emissions in the federative units i and j are possible, including temporal divergence, which refers to the period of $\delta_i \neq \delta_j$. The method proposed by Phillips and Sul (2007) allows to detect convergence even in the case of transition divergence, where other methods, such as stationarity tests applied by Hobijn and Franses (2000) were not effective. Considering equation (4), Phillips and Sul (2007) show that, under the convergence of the variation of the cross section of h_{it}, we have:

$$V_t^2 \sim \frac{A}{L(t)^2 t^{2\alpha}}, \text{ where } t \to \infty \; \forall \; A > 0 \quad (6)$$

from which the regression-based convergence test can be deduced:

$$\log\left(\frac{V_1^2}{V_t^2}\right) - 2logL(t) = a + b\; logt + u_t\,, \quad \forall\; t = [rT], [rT]+1, \dots, T \quad (7)$$

Where, in general, $r \in (0,1)$ and $L(t)$ is a slowly varying function. Phillips and Sul (2007) suggest the use of $L(t) = \log t$ and $r = 0.3$ for sample sizes below $T = 50$. Lastly, using $\hat{b} = 2\hat{\alpha}$, a unilateral t test which is robust to heteroscedasticity and autocorrelation (HAC) is applied to test the inequality of the null hypothesis $a \geq 0$. The null hypothesis of convergence is to reject if $t_{\hat{b}} < -1.65$ (5% significance level). If the convergence was rejected for the general sample, the test procedure will be replicated for the subgroups, following the procedure for testing the clustering mechanism suggested in Phillips and Sul (2007).

4. Results

In this section, the results of the application of the convergence methodology of Phillps and Sul (2007) for the levels of GHG emissions of the federative units of Brazil are presented. A widely discussed fact in society is the issue of global warming, which threatens human well-being and the world economy and the challenge of stabilizing the concentration of GHG (EULER, 2016), which is pointed out as one of the most effective and cost-efficient means for the reduction of deforestation and the loss of forests, as these are responsible for about 12% of global GHG emissions and emissions (VAN DER WERF et al., 2009).

When applying $\log t$ test to GHG emissions in all the federative units in the 1989-2018 period, the hypothesis of general convergence is rejected at the 5% significance level, with the estimate of $b_1 = -0{,}289$, with statistic $t_{\widehat{b_1}} = -426{,}644$ and $b_2 = -1{,}241$ with statistic $t_{\widehat{b_2}} = -8.473{,}774$, respectively for Carbon Monoxide and Carbon Dioxide. Therefore, the series are not converging to a common state, thus, it is possible that the emissions are converging in the form of clubs.

Following the procedures presented by Phillips and Sul (2007), it was possible to identify four groups in the emission of carbon monoxide and three for the emission of carbon dioxide, with two states diverging for CO2. The results of the log *t* test are presented alongside the composition of each club in Table 1, where the estimated parameters and corresponding standard errors are also found, as well as the average emission of CO and CO2 in each club for 1989-2018. In addition, an illustration in the form of maps for the convergence clubs is presented in Appendix A.

Table 1 - Classification of the convergence club

Club	Federative Unit	$\hat{b}$	t-stat.	s.d.
		Carbon Monoxide		
Club 1	AL; GO; MT; MS; MG; PR; PE; RO; SP; TO	0.354	3.398	0.104
Club 2	AC; BH; MA; PB; RN; RJ; SE	0.305	15.204	0.020
Club 3	AM; CE; ES; PR; PI	0.193	6.484	0.030

Club 4	AP; DF; RS; RR; SC	0.108	12.577	0.009
		Carbon Dioxide		
Club 1	AC; AM; BH; CE; GO; MA; MT; MS; MG; PE; PI; RN; RS; RO; RR TO	0.0245	2.1313	(0.0115)
Club 2	AP; PR; PB; SP	0.8863	10.4348	(00849)
Club 3	AL; DF; SC; SE	0.4570	3.3196	(0.1377)
Divergents	ES; RJ	-	-	-

Source: Prepared by the authors.

The descriptive statistics presented in Table 2 shows that there was a significant reduction in relation to the groups formed in CO2 emissions, where emissions reached 2.8 million tons in 1989, decreasing to 1.2 thousand ton, respectively in 2004 and 2016. As for the emission of CO, produced by the Agriculture sector, the scenario diverges, in clubs 3 and 4 the variation shown is negative, indicating a decrease in the CO emission of the sector in groups, in contrast, clubs 1 and 2 have positive variations, suggesting a concerning aspect of the sector's GHG emissions.

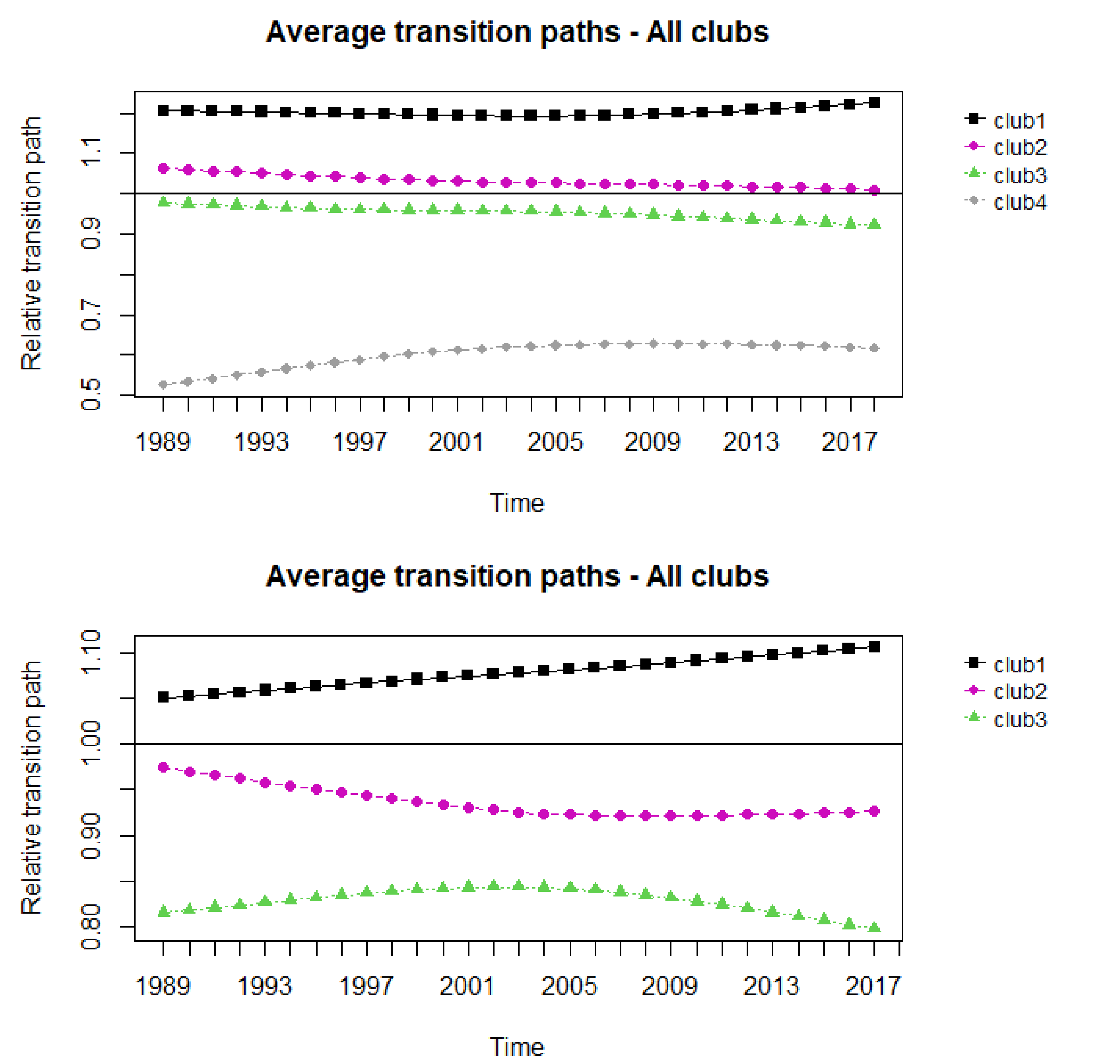
Table 2 - Descriptive statistics and Rate of change - 1989-2018

Club	Federative Unit	Average emission (in tons)	Maximum	Minimum	Variation rate
		Carbon Monoxide			
Club 1	AL; GO; MT; MS; MG; PR; PE; RO; SP; TO	416,581.53	5,786,549	2,975,250	55.5084
Club 2	AC; BH; MA; PB; RN; RJ; SE	45,523.33	388,883	224,310	3.3832
Club 3	AM; CE; ES; PR; PI	17,451.64	126,557	59,171	-18.6374
Club 4	AP; DF; RS; RR; SC	4,389.29	29,935	11,885	-56.3276
		Carbon Dioxide			
Club 1	AC; AM; BH; CE; GO; MA; MT; MS; MG; PE; PI; RN; RS; RO; RR TO	73,872,564.1	2,852,464,395	697,407,848	-21.5527
Club 2	AP; PR; PB; SP	5,499,883.4	45,038,182	7,151,778	-80.9394
Club 3	AL; DF; SC; SE	1,351,477.5	12,364,101	1,258,085	-89.7564

Source: Prepared by the authors.

The steady state trajectory of the clubs can be approximated by the average of the filtered series, as observed in Figure 1 and 2, respectively for carbon monoxide and carbon dioxide. Corroborating with what was featured in the descriptive statistics, it can be seen that agriculture has several challenges in continuing to develop, along with the breaking of paradigms (EMBRAPA, 2014).

Figure 1 - Average transition paths - GHG emissions (CO & CO2), Convergence groups, 1989 - 2018



Source: Prepared by the authors.

As noted above, it can be seen that the trajectory of the steady states of the federative units of Brazil in the first and second CO clubs suggests stagnation, thus, these groups would be very close to having the steady state level of GHG emissions.

In order to analyze the behavior of CO and CO2 clubs before and after the Kyoto Protocol, tables 3 and 4 present the average and variation emissions in each club, before and after the Kyoto Protocol, for CO and CO2, respectively. It can be observed that, in both cases, the average emissions before the Kyoto protocol (1989 – 2004) are lower than after the Kyoto protocol (2005-2018). However, the variation in the post-protocol period is lesser than in the previous one. This is due to the fact that the averages have increased as a result of the economic growth experienced in the country. But the variations have reduced as a result of the commitments in the Kyoto protocol.

[Insert Tables 3 and 4 here]

The identification of the convergence clubs of the Brazilian states in the emissions of carbon dioxide and monoxide by the agricultural sector and in the change in the use of land and forests helps in the formulation of public policies in the sense of directing them to a more assertive strategy, since the initial hypothesis of global convergence was rejected. Thus, policies must be differentiated, and not generalized for all federative units. In this sense, public managers and entrepreneurs must act with different policies for each club.

In relation to carbon monoxide (CO), the states that make up club 1, which has an average emission of 416,581.53 tons, must have stricter policies to control the emission, unlike the other states, especially those that make up the club 4, with an average emission of 4,389.29 tons.

Following the same line of reasoning, now with carbon dioxide (CO2), the states that make up club 1, with an average emission level of 73,872,564.1 tons, cannot have the same policy as the other clubs. Thus, stricter policies are suggested for the states of club 1, given that these states emit high levels of gases, compared to other states in the Union.

As mentioned by Lamb et al. (2021), the prominent global pattern is a continuation of underlying drivers with few signs of emerging limits to demand, nor of a deep shift towards the delivery of low and zero carbon services across sectors, particularly with highder demand for agricultural goods motivating expansion into carbon-dense tropical forest areas. Thus, policies like carbon floor prices and renewable energy subsidies may help (and empirical evidence, such as discussed by the aforementioned author, seems to contribute, even if slightly in some cases), as well as enforcing the adoption of entity emission standards, such as those developed by the international organization for standardization (ISO).

Furthermore, as suggest by Leahy, Clark and Reiseinger (2020), focusing on reducing emissions intensity via productivity improvements and addressing yield gaps is generally accepted as a useful entry point for mitigation, and would be advisable for states in convergence club 1 in Brazil, mentioned previously.

5. Concluding Remarks

In the last decade, there has been a growing need to empirically investigate the hypothesis of clubs of convergences in general, and in particular to identify convergence clubs among the Brazilian states. There is one aspect of this literature that focuses on the endogenous determination of groups that converge to the same steady state level.

In this work, a one-step procedure was suggested to empirically test the hypothesis of global convergence for the 27 Brazilian states, in the 1989-2018 period. Applying the log *t* test (Phillips and Sul, 2007), it was possible to identify the endogeneity existing among the convergence clubs, in addition to indicating that being part of a convergence club does not depend on the initial conditions of each agent.

Thus, the main conclusions were that the null hypothesis of global convergence was rejected, indicating the existence of convergence clubs, which when applying the log *t* test, results suggest the existence of 4 convergence clubs in terms of carbon monoxide emission, and of 3 convergence clubs for the emission of carbon dioxide, respectively, in the sector of agriculture and livestock and in the sector of changes in land and forest use. Even though there is no global convergence among the sectors for the polluting gases studied, it was found that in agriculture there is an improvement in treatment over time, which may explain the attenuated reduction in CO emissions in all groups. On the other hand, the emission of carbon dioxide in the use of land and forests did not decrease in all groups.

With the identification of convergence clubs in Brazilian states in terms of carbon dioxide and carbon monoxide emissions by the agricultural sector, and changes in the use of land and forests, public managers must act with different policies for each club. The different average annual growth rates suggest this.

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APPENDIX A. GROUP SPATIALIZATION FOR GHG EMISSION

Figure 3: CO Emission

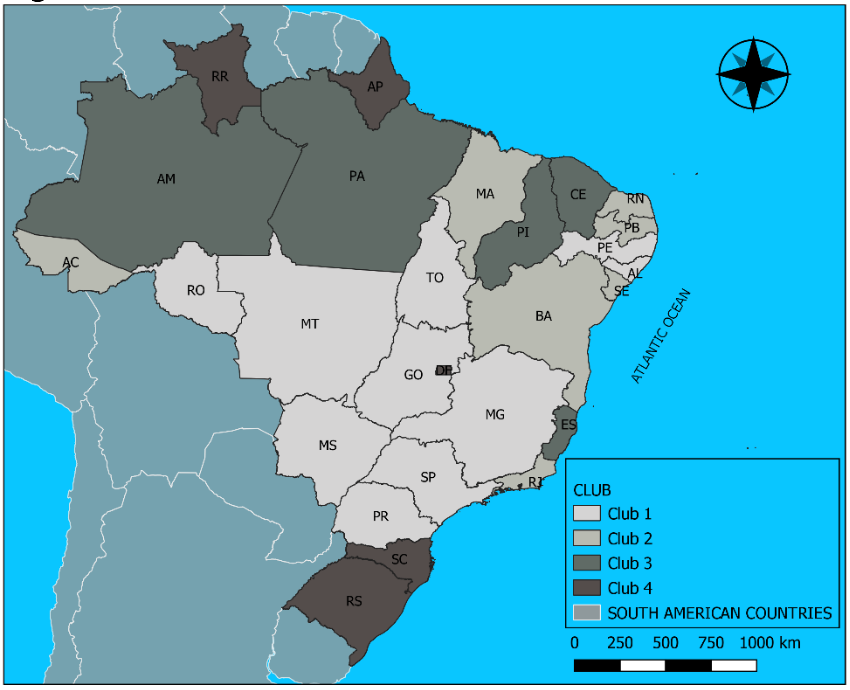
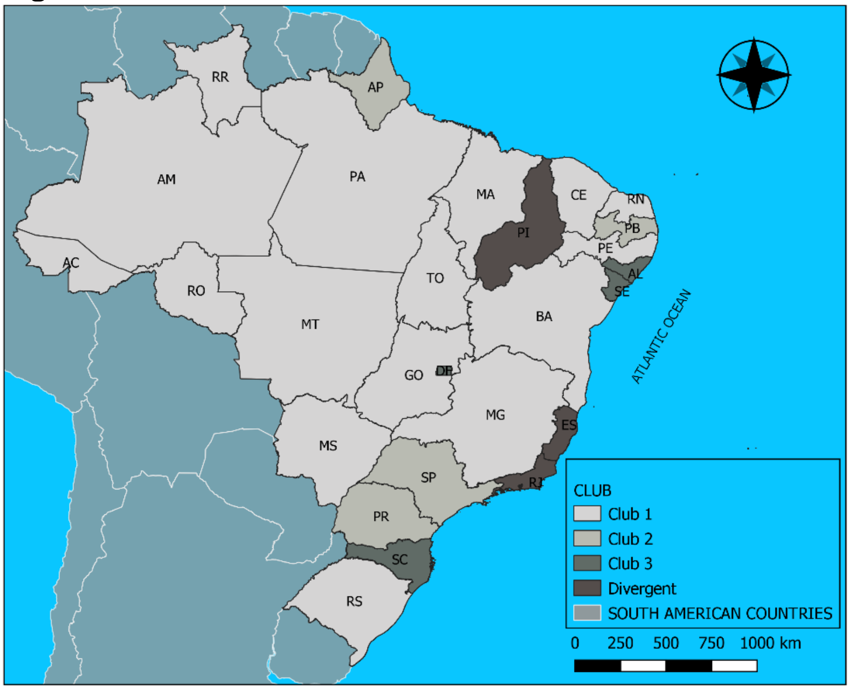


Figure 4. CO2 Emission



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[i] Information was used from 1989 onwards, as that is the year in which the state of Tocantins was created.

[ii] Rejecting cointegration does not necessarily imply an absence of approval or convergence. For more information, see Phillips and Sul, 2007, p.1779.

[iii] As previously mentioned, the series starts in 1989 because that's when there is available data for the state of Tocantins.
[iv] Further details on regularity conditions regarding σ_i and ξ_{it} can be found in Phillips and Sul (2007), p. 1786-1787.