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Determinants of CO_2 emissions in South American and European countries: the economic growth using renewable and non-renewable energy

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Abstract

The objective of this research is to evaluate the impacts of R&D, GDP, income inequality, and renewable energy on CO_2 emissions in countries of South America and Europe. It comprised annual data from 1990 to 2014 obtained from the online World Bank database. The final sample included nineteen countries from South America and Europe. We concluded that there is a positive and significant relation between GDP *per capita* and CO_2 emission, and a negative and significant relation between the percentage increase of renewable energy consumption (in relation to total consumption) and CO_2 emission, confirming the study hypotheses 1 and 3. As a result, (i) the use of renewable energy is fundamental for reducing CO_2 emissions, and (ii) reducing inequality (GINI) results in increased CO_2 emissions.

Keywords: CO_2 emission; GINI; Renewable Energy; World Bank.

Determinantes das emissões de CO2 nos países da América do Sul e da Europa: o crescimento econômico utilizando energias renováveis e não renováveis

Resumo

O objetivo desta pesquisa é avaliar os impactos da P&D, PIB, desigualdade de renda e energias renováveis nas emissões de CO2 em países da América do Sul e da Europa. Inclui dados anuais de 1990 a 2014 obtidos da base de dados online do Banco Mundial. A amostra final incluiu dezenove países da América do Sul e da Europa. Concluímos que existe uma relação positiva e significativa entre o PIB per capita e as emissões de CO2, e uma relação negativa e significativa entre o aumento percentual do consumo de energias renováveis (em relação ao consumo total) e as emissões de CO2, confirmando as hipóteses 1 e 3 do estudo. Como resultado, (i) a utilização de energias renováveis é fundamental para a redução das emissões de CO2, e (ii) a redução da desigualdade (GINI) resulta no aumento das emissões de CO2.

Palavras-chave: *Emissão de CO2; GINI; Energia renovável; Banco Mundial.*

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1 Introduction

The United Nations Framework Convention on Climate Change (2015) acknowledged that climate change is potentially irreversible to the planet and a threat for the survival of humanity. In addition, it recommended the cooperation of nations to mitigate global greenhouse gas (GHG) emissions through the Paris Agreement in the Conference of the Parties Number 21 (COP-21). In this context, Zhu, Duan and Fan (2015), Liu, Wang, Zhang and Kong (2019) and Ji and Zhang (2019) stated that great attention is reported for carbon dioxide (CO_2) emissions compared to other GHGs (e.g., methane and nitrous oxide).

In addition, (i) Machado *et al*. (2015) highlighted that increasing CO_2 emissions is a global concern and needs to be fought along with the reduction of use of fossil fuels, (ii) Salahuddin, Alam, Ozturk and Sohag (2018) stated the need to aggressively invest in researches to achieve better efficiency in power generation and CO_2 emissions, (iii) Gonzáles, Marrero, Rodrígues-López and Marrero (2019) reinforced the need to replace fuel from petrol passenger cars for other alternatives in order to mitigate GHG emissions in Western European Union countries (EU-13), and (iv) Xu, Schwarz and Yang (2019) highlighted a major global concern for China justified by the country's increased CO_2 emissions that could peak in the next 16 years by reinforcing the need to maximize investment in clean technologies (e.g., wind power, photovoltaic energy, and a better efficiency in using natural resources).

Thus, several countries seek mechanisms to produce renewable energy motivated by the decrease in the dependence on fossil fuels by other countries considering the improvement of trade balance, concern for the environment, and reduction of air pollution mainly in large cities (especially cities in China and India) (Kahia, Aïssa & Lanouar, 2017). Zhang, Zhao, Jiang and Shao (2017) reported that China, with a strong economic growth over the last decades, faces enormous pressures from other countries to reduce GHG emissions. Still regarding China, Wang *et al* (2018) portrayed the need for policies to control greenhouse gas emissions by improving energy efficiency. The United Nations Framework Convention on Climate Change (2019), through the upcoming COP25 in Chile, highlighted the need for an effective action on sustainable development, specifically the full implementation of the Paris Agreement of 2015, established and ratified by several countries, including Germany, Brazil, China, India, Japan, and Russia.

Several researches have highlighted the relations between pollution and Gross Domestic Product (GDP) (Esso & Keho, 2016), renewable (and non-renewable) energy (Kahia, Aïssa & Lanouar, 2017), investment in R&D (Lee, Min & Yook, 2015), and income inequality of the population (Wang, Fang & Wang, 2016). In turn, Luzzati, Orsini and Gucciardi (2018), in their research analyzing annual data from 1971 to 2015, emphasized that an active energy policy (i.e., focusing on environmental sustainability) can reduce CO_2 emissions without compromising national economic growth.

Thus, studies were conducted on countries and economic groups around the world to identify the main factors for the increase of GHG emissions, especially in China (Zhang *et al*, 2017; Liu, Wang, Zhang & Kong, 2019), United States of America (Dogan & Turkekul, 2015), Southern Common Market countries (MERCOSUR) (i.e., Argentina, Brazil, Paraguay, Uruguay and Venezuela) (Souza, Souza Freire & Pires, 2018), France (Ang, 2007), Canada (He & Richard, 2010), India (Garg & Shukla, 2009), Algeria (Bouznit & Pablo-Romero, 2016), Turkey (Uzar & Eyuboglu, 2019), European Union (Barker & Köhler, 1998), BRICS (i.e., Brazil, Russia, India, China and South Africa) (Cowan, Chang, Inglesi-Lotz & Gupta, 2014), G7 (i.e., Germany, Canada, United States of America, France, Italy, Japan and the United Kingdom) (Sadorsky, 2009), the G20 (i.e., the 19 largest economies in the world and the European Union) (Yao, Feng & Hubacek, 2015), 38 developed, developing and underdeveloped countries on five continents (Bhattacharya, Paramati, Ozturk, & Bhattacharya, 2016), and other studies on related topics (Baek, 2015; Ben Jebli & Ben Youssef, 2015; Wolde-Rufael & Idowu, 2017).

It is noteworthy the concurrently lack of studies reporting the concomitant impacts of social inequality, R&D investment, GDP, and renewable (and non-renewable) energy on GHG emissions in countries of South America and Europe. Given the previously mentioned research and the aims of this research, the problem of research is: what is the relation of R&D, GDP, income inequality, renewable (and non-renewable) energy and CO_2 emissions with countries of South America and Europe?

This study aims to analyze the impacts of investment in R&D, GDP, income inequality and renewable energy on CO_2 emissions in countries of South America and Europe. To this end, the study uses an approach containing (i) introduction, (ii) literature review and hypothesis development, (iii) methods and data, (iv) analysis of the data used, and (v) conclusion and policy implications.

For practical purposes, this research aims to demonstrate that the use of renewable energy and GDP *per capita* affects, respectively, negatively and positively CO_2 emissions. Investment in R&D should be considered for a sustainable performance (apparently focused only on economic performance to the detriment of environmental concern) and show that the reduction of income inequality does not affect CO_2 emissions (i.e., the results are contrary to those presented by the works analyzed in the research).

2 Literature review and development of hypotheses

Gonzáles, Marrero, Rodrígues-López and Marrero (2019) pointed out that several studies have been carried out specially on greenhouse gas emissions addressing both their determining factors and their implications for the environment. Thus, Ji and Zhang (2019) reported a great concern with China, the country with the highest CO_2 emissions on the planet. The reduction in CO_2 emissions should not without compromise the above-average world economic growth in recent years; in other words, the needs of countries or economic groups should focus on economic development policies that deal with reducing environmental impacts (e.g., incentives for clean energy use and strengthening the trading of carbon credits, highlighted in the Kyoto Protocol, Japan, on December 11, 1997).

The great concern of several countries or economic groups around the world about the increase in CO_2 emission highlights the increasing number of researches with an international scope reporting the preponderant or causative factors of the increase in CO_2 emissions in several developed, developing and underdeveloped countries. Thus, surveys pay attention to the following factors: (i) GDP, (ii) inequality in population income (e.g., GINI Index), (iii) renewable energy and non-renewable energy, (iv) investment in R&D, and (v) concomitant factors.

Several studies have highlighted the positive relation and, in some cases, the co-integration between CO_2 emissions and GDP (Friedl & Getzner, 2003; Ang, 2007; Halicioglu, 2009; Payne, 2010; Pao & Tsai, 2011; Arouri, Youssef, M'Henni & Rault, 2012; Saboori, Sulaiman & Mohd, 2012; Heidari, Katircioğlu & Saiedpour, 2015; Shao *et al*., 2016; Bhattacharya *et al*., 2016; Wang, Ang & Su, 2017; Riti, Song, Shu & Kamah, 2017; Salahuddin, Alam, Ozturk & Sohag, 2018; Soares, Fernandes & Toyoshima, 2018; Meng, Crijns-Graus, Worrell & Huang, 2018, Fethi & Rahuma, 2020; Bresser-Pereira, Araújo & Peres, 2020). For Dogan and Aslan (2017), besides the real GDP, other variables may interfere with CO_2 emissions.

Salahuddin, Alam, Ozturk and Sohag (2018) conducted a study in Kuwait using annual data from 1980 to 2013 and found a relation between economic growth and increased CO_2 emissions. In addition, the research by Dogan and Aslan (2017) with 25 countries and annual data from 1995 to 2011 highlighted that, in addition to GDP, other variables may interfere with CO_2 emissions; the research by Wang, Chen, Kang, Li and Guo (2018) conducted in China using data from 2005, 2008, 2011 and 2015 highlighted that the urbanization and industrial structure, among other factors, are related to CO_2 emissions.

In turn, the negative relation between population income inequality (i.e., GINI Index) and CO_2 emissions is presented in most studies conducted on countries or economic groups (Heil & Wodon, 1997; Padilla & Serrano, 2006; Russ & Criqui, 2007; Wier, Birr-Pedersen, Jacobsen & Klok, 2005; Clarke-Sather, Qu, Wang, Zeng & Li, 2011; Salahuddin & Gow, 2014; Zhang *et al*, 2017; Wang, Fang & Wang, 2016; Soares, Fernandes & Toyoshima, 2018). Uzar and Eyuboglu (2019) conducted a study in Turkey using data from 1984 to 2014 and focusing on environmental degradation and income inequality and noted that increasing income inequality resulted in increased CO_2 emissions.

In contrast, Wolde-Rufael and Idowu (2017), based on information from China (1974-2010) and India (1971-2010) highlighted the lack of significant relations between income inequality and the emission of CO_2. In this context, Liu, Wang, Zhang and Kong (2019) pointed out that a GINI Index close to 0 (1) indicates a low (high) population income inequality. This index is used by many countries and organizations around the world and was created by the Italian Corrado Gini. A positive relation between GINI Index and CO_2 emission is expected (as highlighted in most studies).

Comparing the relation between renewable and non-renewable energy consumption with CO_2 emissions, Inglesi-Lotz and Dogan (2018) analyzed annual data from 1980 to 2011 of Sub-Saharan Africa and reported (i) a positive relation between non-renewable energy (e.g., fossil fuels) consumption and CO_2 emissions and (ii) a negative relation between renewable energy (e.g., wind energy) and CO_2 emissions. Sharif, Raza, Ozturk and Afshan (2019) conducted research on 74 countries using data from 1990 to 2015 and reported a negative relation between renewable energy consumption and CO_2 emissions, recommending the reduction of non-renewable energy use. Li and Zhang (2019) analyzed data from China reporting the need to use renewable energy to reduce CO_2 emissions without compromising economic growth.

Other studies found similar results as those obtained in the work developed by Inglesi-Lotz and Dogan (2018) (e.g., Farhani & Shahbaz, 2014; Dogan & Turkekul, 2015; Jebli, Youssef & Ozturk, 2016; Dogan & Seker, 2016; Adewuyi & Awodumi, 2017; Yang, Lou, Sun, Wang & Wang, 2017; Dogan & Aslan, 2017; Apergis, Jebli & Youssef, 2018). It is worth mentioning the study by Adewuyi and Awodumi (2017), which shows that the relation between economic growth and CO_2 emissions may differ in countries or economic groups. This is justified by global and regional development policies.

The relation of investments in R&D and CO_2 emissions has been analyzed by a great number of studies in several countries or continents around the world, notably in recent years (Lee, Min & Yook, 2015; Ziaei, 2015; Lee & Min, 2015; Shao, Yang, Gan, Cao, Geng & Guan, 2016; Zhang *et al*, 2017; Cho & Sohn, 2018; Gu & Wang, 2018; Jiao, Yang & Bai, 2018; Sim, 2018). Scrivener, Johm and Gartner (2018) highlighted the eco-efficient cements on which investment in R&D has focused and reported that a sustainable development is a key to reducing CO_2 emissions. In addition, Benson and Orr (2008) highlighted investment in R&D as an instrument or mechanism for mitigating CO_2 emissions. In short, previous research mostly exposes a negative relation between investment in R&D and CO_2 emissions.

Considering the determinant factors of CO_2 emission concomitantly, Yao *et al*. (2015) conducted research considering the G20 countries and compared the economic growth with the main factor of increase in CO_2 emission. The authors concluded that an important factor was population growth in Mexico, South Africa, Turkey, and Argentina; and only in economically advanced economies is the use of renewable energy an important factor in mitigating CO_2 emissions. Adewuyi and Awodumi (2017) found a positive relation between GDP, biomass consumption and CO_2 emissions in West African countries. Soares, Fernandes and Toyoshima (2018) conducted a study comprising the sixty largest economies in the world, and the results showed that the largest countries in the world are the highest polluters; however, they are more efficient because technological differences aim to reduce greenhouse gas emissions.

Gu and Wang (2018) pointed out that investment in energy-saving R&D is critical to mitigating GHG emissions, but not important enough to fight global warming. In South Korea, considering the fast development over the last decades, Sim (2018) conducted a study considering investment in R&D related to renewable energy sources and highlighted that the growth of renewable energy production affects both R&D and CO_2 emission reductions. Lee *et al*. (2015) pointed out that investment in environmental R&D affects the corporate environmental performance of companies and the adherence to international environmental agreements.

The study of Souza, Freire and Silva (2018) pointed out a positive relation between GDP and non-renewable energy consumption and CO_2 emissions, and a negative relation between renewable energy consumption and CO_2 emissions in MERCOSUR countries (i.e., Argentina, Brazil, Paraguay, Uruguay and Venezuela). The authors recommended renewable energy sources to ensure energy security for the coming years. Zhang *et al*. (2017) stated that the Chinese government has stepped up investment in R&D to reduce CO_2 emissions in order to reach international environmental goals. In turn, Liu *et al*. (2019) conducted a research with information from 403 Chinese cities and reported that (i) income and CO_2 emissions are positively related and (ii) the relation between the inequality of population income and the CO_2 emission was positive as a double task for the political objective to fight social inequality and GHG emissions.

The studies highlighted several important factors of CO_2 emission in various countries or economic groups around the world either individually (e.g., GDP impacting CO_2 emissions) or concomitantly (e.g., GDP, renewable energy consumption affecting CO_2 emissions). From the focus on the impacts of factors on CO_2 emissions, we highlight the four hypotheses of this research:

H_1 = There is a positive and significant relation between GDP and CO_2 emissions in countries of South America and Europe;

H_2 = There is a positive and significant relation between the GINI coefficient and CO_2 emission in countries of South America and Europe;

H_3 = There is a negative and significant relation between renewable energy consumption and CO_2 emissions in countries of South America and Europe; and

H_4 = There is a negative and significant relation between investment in R&D and CO_2 emission in countries of South America and Europe.

3 Methods and data

For this paper, we chose to use multiple regression through contemporary panel data (i.e., without lags). As the dependent variable, the CO_2 proxy (i.e., carbon dioxide emission in metric tons *per capita*) was used for GHG emissions in accordance with previous researches (e.g., Souza *et al*., 2018; Luzzati, Orsini & Gucciardi, 2018; Xu, Schwarz & Yang, 2019). The sample was consisted by data from 19 countries (i.e., Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, France, Italy, Netherlands, Paraguay, Peru, Russian Federation, Spain, Sweden, Switzerland, Turkey, United Kingdom, Uruguay), i.e., the ten largest European economies and the nine largest South American economies. Venezuela was not considered in the sample due to the absence of complete data (i.e., absence of independent, control or dependent variables) for the analysis period in the database used in the search, i.e., the World Bank.

Data were collected from the World Bank website (http://datatopics.worldbank.org/world-development-indicators/). Information prior to 1990 and after 2014 for *per capita* CO_2 emissions is missing. Finally, it is worth emphasizing the economic importance of the countries adopted as a survey sample, which represent over 85% of the GDP in 2018 and a large part of the population of South America and Europe. Despite the economic importance of the study countries, data cannot be generalized across Europe and South America, being limited to the 19 countries in the sample.

The study is based on several previously highlighted studies focusing on the major factors for GHG emissions in various economic groups, countries or regions around the world. Thus, in order to verify the association between CO_2 emissions (proxy of GHG) and GDP *per capita*, income inequality (GINI Index), renewable energy (% of total energy consumption in the country) and investment in R&D, the following model was formulated:

$$CO_{2_{it}} = \beta_0 + \beta_1 GDP_{it} + \beta_2 GINI_{it} + \beta_3 ER_{it} + \beta_5 R\&D + \varepsilon_{it} \qquad (1)$$

In which:

$CO_{2_{it}}$= Carbon gas emissions in metric tons *per capita*.

GDP_{it}= Real value of Gross Domestic Product (GDP) *per capita* in the US constant for 2010.

$GINI_{it}$= GINI Index, estimating income inequality (with scale from 0 to 1).

ER_{it}= Renewable energy consumption (% of total energy consumption in the country, renewable and non-renewable).

$R\&D_{it}$= Investment in research and development (% of GDP)

Non-renewable energy consumption was considered in the study alongside the renewable energy variable (percentage of renewable energy over the total energy consumed in the country). The control variables adopted in the research were (i) annual value-added growth rate by the agricultural sector (AVA), and (ii) annual value-added growth rate by the industrial sector (IVA). Luo, Long, Wu and Zhang (2017) highlighted the relevance of agricultural and industrial activity for CO_2 emissions, considering data from China of 1997 to 2014. The independent (explanatory and control) variables of the research are highlighted and justified by previous studies and highlighted in the following paragraphs.

As for the variable GDP *per capita*, its increase may result in increased CO_2 emissions, as highlighted in the studies by Friedl and Getzner (2003), Ang (2007), Halicioglu (2009) and Payne (2010). Thus, the higher the GDP, the greater the CO_2 emission. Regarding inequality in distribution, the studies of Wier *et al*. (2005), Clarke-Sather *et al*. (2011), Salahuddin and Gow (2014) and Wang *et al*. (2016) reported a negative relation between income inequality and CO_2 emissions (i.e., positive relation between GINI coefficient and CO_2 emissions).

In turn, with respect to the variable use of renewable energy (compared to the total consumed), it mitigates CO_2 emissions especially in recent years, as highlighted by the studies of Farhani and Shahbaz, (2014), Dogan and Turkekul (2015), Jebli *et al*. (2016), Adewuyi and Awodumi (2017), Dogan and Aslan (2017) and Yang *et al*. (2017). Thus, the higher the use of ER, the lower the CO_2 emission. The last explanatory variable, investment in R&D, is of paramount importance for the pursuit of economic and sustainable development, the pursuit of profitability, and the preservation of the environment (Lee *et al*., 2015). Zhang *et al*. (2017) reported that an increased investment in R&D, considering economic and environmental performance, could reduce CO_2 emissions.

Finally, considering the control variables, the IVA was considered by the industrial sector as one of the main factors responsible for GHG emissions (Ouyang & Lin, 2015; Kagawa, Suh, Hubacek, Wiedmann, Nansai & Minx, 2015). The study expected a positive relation of the variable with CO_2 emission. In turn, the second AVA control variable was considered by the agricultural sector also as one of the major emitters of CO_2 (although the productivity obtained by agriculture has advanced in recent years) (Paustian, Cole, Sauerbeck & Sampson, 1998; Burney, Davis & Lobell, 2010). Thus, the increase in value-added by agriculture is expected to result in increased CO_2 emissions.

4. Analysis and discussion of result

This study analyzes the impact of R&D, GDP, income inequality and renewable energy (non-renewable) on CO_2 emissions for the countries of South America and Europe. Initially, descriptive statistics were performed and the estimates were presented later (with multiple regression and panel data) and their respective validation or robustness tests.

The descriptive statistics of the variables presented in table 1 showed that: i) the average CO_2 emission per capita in the countries of Europe is 3.4 times the average CO_2 emission by the countries of South America; ii) South American countries use on average 24.48% of renewable energy in relation to the total consumed, being higher than the average used in Europe, iii) the GINI coefficient is better (i.e. lower) in Europe, being close to 0.34, in comparison with South America, with an index close to 0.50, iv) South America's GDP per capita represents only 16% of the GDP of European countries, v) South America's gross domestic expenditure on research and development (R&D) accounts for only 0.36% of GDP, which is low compared to Europe which invests 1.71% and vi) The highest per capita CO_2 emissions per nation is 4.76 and the lowest is

0.49. It is worth reiterating that not all countries in South America and Europe were considered in the research.

Table 1 - Descriptive statistics south America and Europa

	Variable	Median	Mean	Standard Deviation	Max.	Min
South America	CO_2	2.03	1.72	1.10	4.76	0.49
	GDP (in U$)	4,898	3,920	3,682	16,230	720
	GINI (in %)	50.56	50.80	5.34	61.60	39.50
	ER (in %)	24.12	24.48	14.95	58.02	0.60
	R&D (in %)	0.36	0.30	1.19	0.30	0.05
	IVA (in %)	1.93	1.68	4.39	16.49	-13.97
	AVA (in %)	2.08	2.19	5.97	39.52	-26.10
Europa	CO_2	7.50	7.07	2.58	13.97	2.70
	GDP (in U$)	30,244	28,460	17,938	88,740	1,710
	GINI (in %)	34.17	33.80	4.67	48.40	25.30
	ER (in %)	20.84	13.03	19.87	79.15	1.16
	R&D (in %)	1.71	1.64	0.79	3.91	0.37
	IVA (in %)	2.19	2.35	5.27	19.13	-21.59
	AVA (in %)	2.06	2.19	7.77	41.16	-27.86

Source: Research data.

In summary, considering the descriptive statistics, Europe and South America present differences, mainly (i) GDP per capita, (ii) income inequality (GINI Index), (iii) investment in R&D and (iv) Co2 emissions. In order to ensure the robustness of the estimates (i.e. non-biased estimates) performed in the survey, the following assumptions were met: (i) autocorrelation, (ii) normality, (iii) heteroscedasticity, (iv) stationarity and (v) multicollinearity. Perform the unit root test, (i) Levin, Lin and Chu (LLC) of 2002 and (ii) Im, Pesaran and Shin (IPS) of 2003. Highlighted in Table 2 are the stationary variables at the level of GDP (at 5% level), GINI (at 1% level), IVA (at 1% level) and AVA (at 1% level) and first difference (variation) (at 1% level) for the variables CO_2, ER and R&D.

Table 2 - Unit root test (LLC and IPS)

	LLC		IPS	
VARIABLES	Level	Variation	Level	Variation
GDP	-2.50***		-2.23**	
GINI	-7.56***		-4.02***	
ER	1.15	-16.75***	1.83	-15.95***
R&D	-2.82***	-11.38***	-0.34	-5.84***
IVA	-10.28***		-10.31***	
AVA	-18.92***		-21.26***	
CO_2	0.83	-14.30***	0.73	-14.70***

Source: Research data.

Table 3, in turn, highlights the correlations between the research variables. It is noteworthy that the Variance Inflation Factor (VIF) tests were not reported, what leads us to conclude that multicollinearity is not a problem for the research estimates. Thus the highest correlations were for (i) GDP per capita and R&D, (ii) GDP per capita and GINI Index, (iii) CO_2 emission and GINI index and (iv) CO_2 emission and R&D.

Table 3 - Correlation of variables

VARIABLES	GDP	GINI	ER	R&D	IVA	AVA
GINI	0.75					
ER	0.07	-0.09				
R&D	0.85	-0.72	0.22			
IVA	0.06	-0.08	0.10	0.09		
AVA	0.03	-0.01	0.10	0.06	0.12	
CO_2	0.49	-0.68	-0.35	0.53	0.04	-0.02

Source: Research data.

For autocorrelation, the Durbin-Watson (DW) test of 1951 highlighted the absence of autocorrelation. For heteroscedasticity, data were estimated through White (diagonal) Test. Finally, for normality, the Central Limit Theorem was used as a support, in which samples larger than 100 observations tend towards normality (Gujarati & Porter, 2011). The results presented in Table 4 (control variable estimations performed using the Eviews 8 system) were performed with Pooled, with better adjustment. To determine the best fit, the Chow tests (option between pooled and fixed effects) and the Hausman test (option between fixed effects and random effects) were performed. Estimation A reported an R^2 of approximately 18.47% and Estimation B reported an R^2 of approximately 19.05%, slight variation by excluding a variable (i.e. IVA).

Table 4 - Results for CO_2

VARIABLES	A	B
GDP	-1.56e-06***	-1.57e-06***
GINI	-0.0011*	-0.0011*
D(ER)	-0.011**	-0.012***
D(R&D)	-0.098	-0.106
IVA	0.001	
D(AVA)	0.000*	0.000*
C	0.078***	0.084***
Efects	*Pooled*	*Pooled*
R^2	0.1905	0.1847
F	7.25 (0.0000)	8.42 (0.0000)

Source: Research data.

Through estimates (Table 4), A and B, performed with control variables and also intecept it is possible to verify the confirmation (rejection) of the research hypotheses. Regarding H1, GDP per capita showed a positive and significant relationship at 1% with the dependent variable (CO2) in the estimates made, confirming the first hypothesis and corroborating the research of Halicioglu (2009), Payne (2010), Riti, Song, Shu and Kamah (2017), Soares, Fernandes and Toyoshima (2018), Meng, Crijns-Graus, Worrell and Huang (2018) and Salahuddin, Alam, Ozturk and Sohag (2018) performed in other countries.

In turn, H2 was not confirmed, once the GINI coefficient showed a negative and significant relationship at 10% with CO_2, not confirming with the results of the previous studies (Wier *et al*., 2005; Clarke-Sather *et al*., 2011; Salahuddin & Gow, 2014; Wang *et al*., 2016; Uzar & Eyuboglu, 2019). In other words, lower income inequality does not imply lower CO_2 emissions. The unexpected signal relationship may be justified by regional developmental features or policies (e.g. Adewuyi & Awodumi, 2017; Wolde-Rufael & Idowu, 2017) intrinsic to the survey sample countries.

Also, the percentage increase in renewable energy consumption (in relation to total consumption) has a negative and significant relationship at 5% (1%) in Estimate A (B) with CO2, confirming H3 in line with (done in various countries around the world) Farhani and Shahbaz (2014), Dogan and Turkekul (2015), Jebli *et al*. (2016), Adewuyi and Awodumi (2017), Dogan and Aslan (2017) and Yang *et al*. (2017, Apergis, Jebli and Youssef (2018) and Sharif, Raza, Ozturk and Afshan (2019).

Finally, investment in R&D did not show a significant relationship at 10% with CO_2, and H4 was not confirmed, so we conclude it is in disagreement with the results of Lee *et al*. (2015) and Zhang *et al*. (2017), Cho and Sohn (2018), Gu and Wang (2018), Jiao, Yang and Bai (2018) and Sim (2018). The lack of relationship can possibly be justified by the R&D investment with a preponderant focus on economic performance over the sustainability focus on R&D investment described by Scrivener, Johm and Gartner (2018).

In Estimate A, two control variables were used and in Estimate B (in the absence of a significant 10% IVA ratio in Estimate A) only one AVA control variable was adopted. Regarding the AVA control variable, the positive and significant relationship at 10% in the estimates is confirmed, what corresponds to the expected results. Otherwise, the increase in value added by agriculture positively impacts CO_2 emissions, in accordance with the research of Burney, Davis and Lobell (2010).

The relationship between the value added by the industrial sector (IVA) and the CO2 emission was not confirmed, what differed from the results presented by Ouyang and Lin (2015) about a negative relation of variables. This can be probably justified by the fact that the industrial sector of the research countries did not adopt a consensus that increased productivity would demand a greater control of CO_2 emissions. The intercept showed a positive and significant relationship at 1% in both research estimates.

5 Conclusion and policy implications

To achieve the research objective four hypotheses were formulated: H1 - there is a positive and significant relationship between GDP and CO_2 emissions in the countries from South America and Europe; H2 - there is a positive and significant relationship between the GINI coefficient and CO_2 emission in the countries from South America and Europe; H3 - there is a negative and significant relationship between renewable energy consumption and CO_2 emissions in the countries from South America and Europe; and H4 - there is a negative and significant relationship between investment in R&D and CO_2 emissions in the countries from South America and Europe. Noting that the results cannot be generalized to all South American and European countries.

Based on the estimates (A and B) made in the research, containing multiple regression with control variables of the industrial and agricultural sectors, hypotheses 1 and 3 were confirmed: a positive relationship between GDP per capita and CO_2 emissions and a negative relationship between the percentage increase in renewable energy consumption (in relation to total consumption) with the emission of CO_2. Also, only the AVA control variable showed a positive and significant relationship at 10%.

Hypotheses 2 and 4 were not confirmed in the research, once the reduction of the GINI coefficient (reduction of income inequality) and the increase of investment in R&D did not imply a reduction of CO_2 emissions. With respect to the policy implications and recommendations, South America and Europe could (i) seek to increase consumption of renewable energy (e.g. reduction of income tax of companies using only renewable energy in their production processes), (ii) improve investment in R&D (specifically, focusing on clean technologies) and (iii) focusing on economic development mechanisms focused on environmental sustainability.

In other words, economic development mechanisms with tax incentives and better financing conditions aimed at ensuring environmental sustainability. In time, income inequality should also be considered in the development policy of the regions, highlighted in South America with the GINI index of 0.50.

For future research, we suggest: (i) it would be interesting to work on the full and segregated estimation of developed, developing and underdeveloped countries of economic groups, not addressed in the previous literature, (ii) sample present on all continents with a longer period of analysis, (iii) inclusion of other hypotheses for the research and (iv) use of other metrics as a proxy for greenhouse gas emissions with other econometric estimation methods or techniques.

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