Universidade de Évora - Escola de Ciências Sociais

Mestrado em Economia

Dissertação

The environmental Kuznets Curve for Brazil.

Mariana Akemi Takano

Orientador(es) | José Manuel Madeira Belbute

Évora 2020

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A dissertação foi objeto de apreciação e discussão pública pelo seguinte júri nomeado pelo Diretor da Escola de Ciências Sociais:

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Évora 2020

A curva ambiental de Kuznets para o Brasil

Resumo

A teoria *Environmental Kuznets Curve* baseia-se no pressuposto que os países passam por uma trajetória de impacto ambiental semelhante ao crescimento económico. Este estudo busca estabelecer uma relação empírica entre as emissões de CO_2 e o PIB per capita, aplicada ao Brasil no período 1960-2014. O objetivo é verificar a existência desta relação empírica e determinar o formato da EKC. Os resultados indicam uma relação em forma de U invertido entre o PIB e o CO_2, além de uma proximidade ao ponto de viragem, estimado em 12.205,13 USD. Com efeito, a partir deste ponto, as emissões podem diminuir enquanto que o PIB aumenta. Os resultados também demonstraram que o Brasil, com seu atual modelo de importações, não está impondo emissões para outros países. Estes resultados podem ter grandes implicações, ao sugerirem que a descarbonização da economia teria um impacto económico positivo, num futuro próximo, sem comprometer o crescimento económico.

Abstract

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The Environmental Kuznets Curve hypothesis depends upon the assumption that countries go through a similar environmental impact trajectory as they experience income growth. This dissertation establishes an empirical relationship between CO_2 emissions and gross domestic product per capita for Brazil over the period 1960-2014. The aim is to verify the existence of this empirical relationship and determine the EKC format. Findings indicate that GDP is related to CO_2 in an inverted U-shaped relationship and Brazil is current near to the turning point, which was estimated in 12.205,13 USD. Indeed, from this point, CO_2 emissions may decrease as GDP increases. Also, results showed that Brazil, with its current import pattern, is not imposing emissions to other countries. These conclusions may have strong policy consequences because it suggests that decarbonization of the economy will spontaneously lead to positive economic impact in the near future and would be not compromising economic growth.

Keywords: GDP, CO_2, Brazil, EKC, Environment.

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1. Introduction

The environmental concerns related to energy consumption have been held a prominent place in the academic community. This is observed by a large number of studies and researches aiming to find a balance between economic growth and environmental preservation. Recent world economy growth based on carbon-intensive activities has led to rapid expansion of fossil fuel CO_2 emissions. This fact has been concerning people from all over the world due to the shown effects of rising CO_2 emissions such as global warming and natural disasters.

According to Olale et. al (2018), there is also a consensus that human activities are responsible for recent global warming and, consequently, many countries are trying to establish the best policies that can drive down greenhouse gas emissions to slow down climate change.

Recently, the IPCC (2018) report has pointed that limiting global warming to 1.5°C would require "rapid and far-reaching" transitions in land, energy, industry, buildings, transport, and cities. Global net anthropogenic emissions of CO_2 would need to fall by 45% from 2010 levels by 2030, reaching 'net zero' by 2050. It also states that in this scenario of 1.5°C pathways with no or limited overshoot, renewables are projected to supply 70–85% of electricity in 2050.

As the IPCC (2018) suggests the natural carbon sequestration capacity will be approximately 15% of the 2010 levels while carbon neutrality implies by 2050 a reduction of 85% relative to 2010 levels. According to this report, carbon dioxide removal (CDR) would be used to compensate for residual emissions. In most cases, to achieve net negative emissions to return global warming to 1.5°C following a peak. Also, all projections show a CDR decrease in the order of 100–1000 $GtCO_2$ over the 21st century.

According to IPCC (2018) "Estimates of the global emissions outcome of current nationally stated mitigation ambitions as submitted under the Paris Agreement would lead to global greenhouse gas emissions in 2030 of 52–58 GtCO2eq yr-1."

In light of recent advances in studies [e.g., Frankel and Rose (2005); Pao and Tsai (2011); Sugiawan and Managi (2016); Balaguer and Cantavella (2018); and Dong et al. (2018)], it is imperative to know if there is a trade-off between pollution and growth in order to pursue sustainable development. In this field, this dissertation aims to empirically test the hypothesis of the Environmental Kuznets Curve existence for Brazil, and if it exists, which type of relationship is about.

The main goal is significant since the non-rejection of our hypothesis would allow us to answer other related research questions. Specially, is it possible to integrate economic growth with the economy's decarbonization? If so, from which point?

In order to answer the above questions, we are going to test linear, quadratic and cubic econometric models. The determination of environmental and economic effects from CO_2 emissions combined with GDP per capita of Brazil might help the decision-makers to obtain a relational panorama and its consequences regarding people's life quality and the environment.

Our hypothesis is that there is a robust relationship between CO_2 emissions and economic development. In addition, we can also test other hypotheses, such as the Pollution Haven Hypothesis, analyzing which commodity-importing countries may be "exporting" environmental impacts to their suppliers [see, among others, Stern et al., (1996) and Friedl and Getzner (2003)].

This dissertation is relevant from an economic point of view since there are few studies with these relational particularities applied for Brazil. It is important to emphasize that Brazil has some distinctiveness such as an extensive forest area, as known as the Amazon rainforest, and historically major emissions concentrated in agriculture, forestry, and other land use, associated with deforestation, cropping and livestock (La Rovere, 2018).

The Brazilian territory has an area of 8,514,876 km², which gives the fifth position, considering the largest area on the planet, just behind Russia, Canada, the United States, and China. Brazil's large territorial area gave it a denomination of country with "continental dimensions," in which Legal Amazon has an approximate 5 217 423 km² of surface area, corresponding to about 61% of the Brazilian territory (IBGE, 2014).

It should be noted that contrary to popular belief, the fact that most of the Amazon rainforest is in Brazilian territory has no implications for the Brazilian total CO_2 emissions sequestration capacity since the Amazon rainforest consumes all the oxygen that it generates. However, the relevance of the Amazon rainforest to the problem of climate change lies in its effect on the general atmospheric circulation, which makes its exploitation /extinction particularly relevant.

Another relevant fact related to carbon dioxide emission is Brazil's position and contribution to greenhouse gas (GHG) emissions worldwide. Brazil is on the 13th position in the ranking of the most CO_2 emitters in the world, while the first positions are held by China, the United States, and India, respectively. The Brazilian contribution was about 1.3% of the global emission in 2017 (Atlas, 2019).

From the economic point of view, Brazil is part of G20, the world's leading economic governance group. Together, the countries of this group represent 90% of world GDP, 80% of international trade and two-thirds of the world's population. For these reasons, the group can influence the international agenda, promoting debates on the main global challenges and taking joint initiatives to promote inclusive economic growth and sustainable development (Brazil, 2019b).

Also, Brazil is member of the BRICS, which represents a group of five major emerging countries (Brazil, Russia, India, China, and South Africa), accounting together for 42% of the population, 23% of GDP, 30% of the territory and 18% of trade worldwide (World Bank, 2019). In addition to its economic importance, BRICS have a significative influence on world politics. According to Amorim (2010), BRICS hold significant territorial extension, energy resources with considerable diversity and quantity, and large technological development.

Thus, this research may also contribute to a better understanding of the relationship between economic growth and pollutant gaseous emissions, with emphasis on carbon dioxide, by proving existing relations between them. The study has the potential to provide useful information to policymakers about the feasible standard for the decarbonization efforts which the refed countries need to fulfill their commitments assumed on the Paris Agreement. With this study, we intend to contribute to the discussion about Brazil's commitment to the decarbonization of the national economy, aligned with the Paris agreement and the IPCC recent targets for 2050.

2. Literature Review

2.1. The Environmental Kuznets Curve

Energy may contribute to improving people's lives since it helps in many aspects such as fighting hunger, improving sanitary conditions and gender equality. In a social aspect, energy contributes to the efficiency of public intervention once it can improve information exchange and rationalize public transportation. From an economic point of view, energy can lead to improve productivity and diversify the economy. In other words, energy plays an essential role in a virtuous cycle of human, economic and social improvements that are crucial to get sustainable development in emerging countries (Kaygusuz, 2012). These interactions are shown in figure 1.

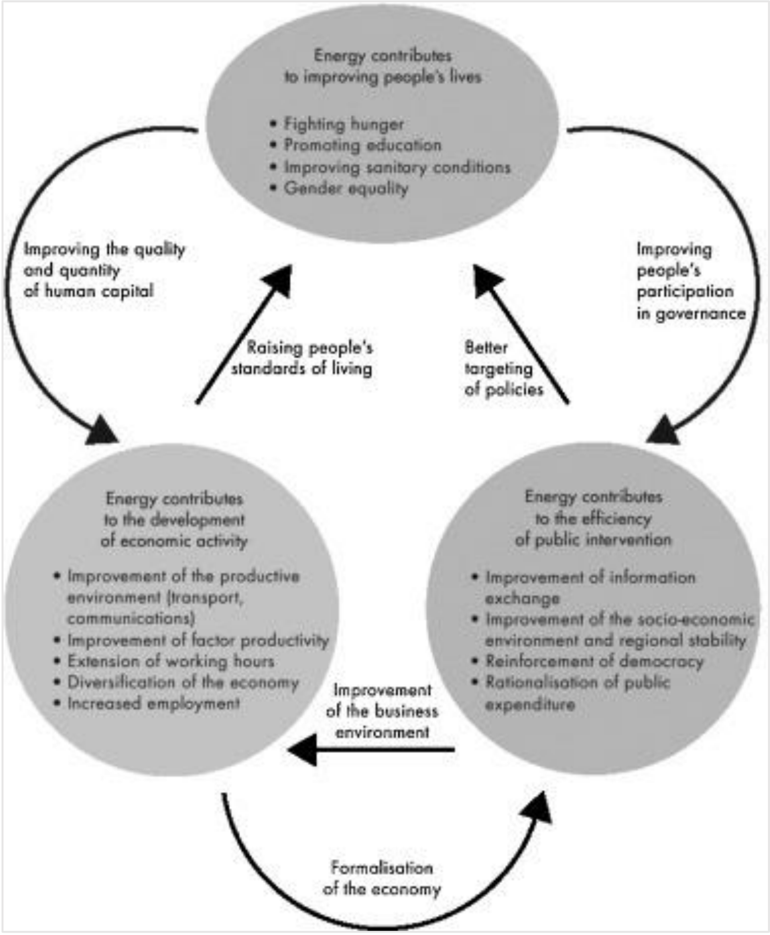


Figure 1: Connection between energy and human, economic and social development (Kaygusuz, 2012)

Sufficient supplies of clean energy can be considered as the basis for raising standards of living, enhancing the quality and quantity of human capital, improving the business and natural environment, and growing the efficiency of government policies (Teske et al., 2012).

Moreover, energy poverty remains a major problem for human health, economic development and environmental sustainability in many parts of the world, especially in developing economies (Kaygusuz, 2012).

According to Kaygusuz (2012), the challenges of long-term energy security and environmental sustainability can be solved within the deployment of efficient and less expensive technologies, which are able of using more plentiful, cleaner and cheaper sources of energy. The author believes that better technologies need to be developed and implemented in order to keep improving current clean energy technologies. Also, it is important that energy policy is harmonized and coordinated to promote sustainable energy innovations and research policy on this theme.

Energy is considered as an essential input for manufacturing processes. Because energy consumption is so massive among the industries, continuous energy supply is required for maintaining and improving ongoing manufacturing level and living standards in any country, whether is the country is developing, emerging, developed or industrialized (Alam et al., 2016). Environmental scientists say that energy consumption is the main responsible for carbon dioxide (CO2) emission, which is one of the Greenhouse Gases (GHG) responsible for global warming and climate change (Alam et al., 2016).

Greenhouse gases are responsible to absorb part of the infrared radiation emitted by the Earth’s surface, blocking their passage to space, as a normal process. Although, a high concentration of GHGs in the atmosphere enhances the greenhouse effect, causing the rising of Earth’s temperature. This situation occurs mainly due to the use of fossil fuels as the main source of global energy (dos Santos, 2014).

Since 1990, CO_2 emissions from energy consumption have significantly boost in newly industrialized countries compared to industrialized countries (Kasman and Duman, 2015). According to the authors, environmental quality degradation has achieved alarming levels and brought out concerns about global warming and climate change. Thus, understanding the causes of environmental deterioration and its relationship with economic growth become increasingly decisive over recent years.

Due to the rapid growth in energy consumption, the limited reserves and non-renewable characteristics of fossil fuels, and the environmental pollution caused by the massive use of fossil energy, clean energy has been developed with improvements in energy efficiency (Liu et al., 2015). In this context, renewable energy sources such as wind and solar power have been widely applied to the field of power generation (Ludin et al., 2014). This development has great significance in order to solve energy shortage issues and reduce environmental pollution (Santoyo-Castelazo and Azapagic, 2014).

In order to dissociate carbon dioxide emissions from economic growth has become a general strong desire since fossil fuel consumption has been, in large part, attributed to economic growth. Governments are committed to scaling down greenhouse gas emissions without damaging their economic development based on the assumption that more economic growth does not always lead to increased emissions (Bento and Moutinho, 2016).

Carbon emissions do not necessarily depend on their income level alone. Energy consumption, foreign trade, and financial development should also be considered as factors that can affect carbon emissions in a country. Because of it, researchers have attempted to include not only output/income or economic development but also enlarge their analysis for financial development or for variables capturing openness or trade intensity of a country (Zhang, 2011).

The foreign trade intensity in an economy might have an important implication on the level of country’s pollution since the literature emphasizes the relationship between carbon emission and foreign trade as a fact that pollution is generated during the goods’ production and it is linked to consumption in another country.

The impact of economic growth, energy consumption and trade openness on the environment has become a dominant question in the economic literature, in recent years. Many companies have been using global sourcing as a corporate level strategy, since industrial revolutions. According to Khan et al. (2016), global sourcing has extensive power to affect environmental sustainability as a result of enormous involvement in transportation and long lead-time. United Nations (2014) demonstrates some compelling facts about transportation, showing that almost 22% of worldwide carbon dioxide emissions can cause a negative environmental externality on humans' life and several diseases including lung cancer, ischemic heart disease, and others.

In the last few decades, pollutant emissions are considered under the heading of the major worldwide current concerns. Worldwide organizations, such as the United Nations (UN) or the World Economic Forum (WEF), have been focused on decrease the impacts of global warming and climate change on the economy (Farhani et al., 2014).

Sustainable development is progressively being presented as a pathway to have a more desirable society. Although, there is not any political or scientific agreement on a definition of sustainable development yet. It is still reminding as an ideal political concept, similar to democracy, justice, and liberty (Meadowcroft, 2007).

There are many definitions of sustainability. According to Johnston et al. (2007) “It seems clear that sustainability can mean a number of things to a variety of constituencies and, while there may be no objection to the sentiments expressed in the respective definitions, they are far from holistic.” Ehrenfeld (2005) said that “I define sustainability as the possibility that all forms of life will flourish forever”. McMichael et al. (2003) define sustainability as a process of transforming our ways of living in order to maximize the possibilities that environmental and social conditions will support human security, well-being, and health for an unlimited time.

On the other hand, Kates et al. (2005) combining three major categories of what is to be sustained (life support systems, nature, community) with what is to be developed (economy, people, society). The authors also recognized four different family definitions based on goals, indicators, practices, and values. As a result, they come over with an incredible list of definitional components, contained ecological services (climate, clean air, land productivity, and others), societal characteristics (peace, dignity, equity, and others) and human values (tolerance, freedom, respect for nature, and others).

According to White (2013), the term “sustainability” is commonly used by at least two communities, one focusing on sustainable development (SD) and the other on sustainability science (SS).

The concept of sustainable development (SD) appeared in the context of environmental concerns endorsed by the first term presence in the World Charter for Nature (UN, 1982). These matters were discussed in Our Common Future (WCED, 1987) and further expanded in 40 Chapters of Agenda 21 of the Earth Summit in 1992 (UN, 1992). In the sequence of this, the World Summit on Social Development in Copenhagen in 1995 (UN, 1995) emphasized SD’s key role in securing global social development and added this “third pillar” to the current definition of SD reinforced by the World Summit in 2002, on Sustainable Development in Johannesburg (UN, 2002) and many subsequent documents. There are many SD indicators and indices already established and new metrics are in their way to appear (e.g. Bandura, 2008; Tasaki et al., 2010).

Sustainable development continues to be an important concept, which was discussed at the United Nations Conference on Sustainable Development (Rio+20), held in Rio de Janeiro in June 2012. In this conference, the agreement by member states to define sustainable development goals was one of the conference’s main outcomes. This demonstrates that achieving sustainable development is still an actual theme on the international and national agendas 25 years after the concept was cited in the publication of Our Common Future, commonly referred to as the Brundtland Report (WCED,1987).

The Brundtland Report states that: ‘‘Sustainable development clearly requires economic growth in places where such [human] needs are not being met. Elsewhere, it can be consistent with economic growth, provided the content of growth reflects the broad principles of sustainability and non-exploitation of others. But growth by itself is not enough’’ (WCED, 1987, p. 44).

Sustainable Development Goals (SDGs) are entrenched in a policy frame, in other words, the development of the SDGs went through a political process and the Zero Draft progress from broad political negotiations. The conceptualization of sustainability evaluation and operationalization considering goals and targets should follow certain agreed principles. The Zero Draft requires the targets to be followed by relevant indicators set by United Nations Statistical

Division (2015) based on several selections such as relevance, methodologically sound, measurable, accessible, restricted in number and outcome-focused.

In 2000, the UN Millennium Declaration was signed by 189 countries, and it defined eight Millennium Development Goals (MDGs) for development and poverty eradication. These goals are intended to be achieved by 2015, aiming to address extreme poverty in its many dimensions such as income poverty, hunger, disease, lack of adequate shelter, and exclusion. The MDGs also have the intention of promoting education, gender equality, and environmental sustainability, with quantitative targets (Sachs and Mcarthur, 2005).

In September 2015, the United Nations General Assembly embraced 17 Sustainable Development Goals (SDGs) as an integral part of the 2030 Agenda for Sustainable Development (Assembly, 2015). The SDGs promise an innovative type of governance with global goals defined by the UN member states, which represent the most ambitious effort to place goal setting at the center of global policy and governance. These 17 goals were built on the scope of the earlier Millennium Development Goals (MDGs), which expired in 2015. The SDGs can be considered a historic turnover for the UN in order to achieve a sustainable development agenda, after a long history of trying to integrate economic and social development with environmental sustainability (Biermann et al., 2017).

The SDGs aspire for universal application, in other words, to be global in nature. They are also intended to be appropriated for national and local contexts by considering several factors, such as the level of development and existing national and local policies (Biermann et al., 2017). According to the author, the SGDs can be recognized as a significant departure from the MDGs that had been established at the global level, so it has been often criticized for its ‘one-size-fits-all’ approach (Kanie and Biermann, 2017). Gupta and Nilsson (2017) emphasize that the transcription of global aspirations into national policies needs essential capacities at the national level, including functioning governance systems in order to have success in their actions.

The MDGs were substantially related to a traditional economic and social development agenda while the SDGs attempt to integrate the three pillars of sustainable development (economic, environmental and social) with the 17 goals that simultaneously cover all three aspects

(Biermann et al., 2017). Also, according to the author, integrating these aspects with their different agendas and actions in the implementation of the SDGs is a key challenge for decision-makers at all levels of governance. Sustainable development definitions and measurement are the keys to success in the United Nations' Sustainable Development Goals (SDGs). The ability to measure sustainable development would enable us to understand the status of the world by checking progress in achieving sustainability.

The climate change issue is one part of the largest challenge of sustainable development, consequentially, climate policies can be more effective to make national and regional development paths more sustainable. The impact of climate change, climate policy responses, and associated socio-economic development will affect countries' capacity to accomplish sustainable development goals (Sathaye et al., 2006).

Global warming will still continue for several decades and sea levels will continue to rise for many centuries even if stabilization of greenhouse gases is reached. IPCC (2018) studies make clear that developed countries alone cannot achieve this reduction, even if their emissions were reduced to zero in the near future. The current trends of growing emissions from developing countries could make the atmospheric concentration to exceed stabilization levels. The participation of all countries, including the developing ones, is crucial for a successful worldwide effort to detain greenhouse gas emissions growth.

The IPCC (2018) report finds that limiting global warming to 1.5°C would require "rapid and far-reaching" transitions in land, energy, industry, buildings, transport, and cities. "Global net human-caused emissions of carbon dioxide (CO2) would need to fall about 45 percent from 2010 levels by 2030, reaching 'net zero' around 2050" (IPCC, 2018). This statement means that any remaining emissions would require to be stabilized by removing CO_2 from the air. For this reason, it is essential to have a better understanding of the relationship between economic growth, energy consumption, and foreign trade, in order to acquire and spread a strong knowledge basis for helping police makers to set objectives considering the whole scenario.

Some studies employ a multivariate framework in order to verify the relationship between economic growth, energy consumption and pollution emissions like Lean and Smyth (2010). The authors found the long-run relationship in five ASEAN (Association of Southeast Asian Nations) countries implying the existence of a statistically significant positive association between electricity and emissions, and a non-linear relationship between emissions and real output, consistent with the EKC. The Granger causality test results indicate that there is unidirectional Granger causality running from electricity consumption and emission to economic growth in long-run, and unidirectional Granger causality running from emissions to electricity consumption in the short-run.

Soytas and Sari (2009) discovered a unidirectional Granger causality running from energy consumption to pollution emissions. On the other hand, Zhang and Cheng (2009) found unidirectional Granger causality running from economic growth to energy consumption and energy consumption to pollution emissions.

Grossman and Krueger (1991) introduced the Environmental Kuznets Concept in their innovative study of the potential impacts of the North American Free Trade Agreement (NAFTA). The authors´ main focus was on the hypothesis that increasing growth might lead to environmental quality improvements in Mexico rather than reducing. For the empirical analysis, they considered the relationship of Gross Domestic Product per capita (GDP per capita) as an income indicator and air pollutants, which were SO_2 and Suspended Particulate Matter (SPM), as environmental indicators. The data used to support their theory and to run the empirical model was taken off from the GEMS database and covered various time periods from 42 countries. As a result, they found EKC existence, and they concluded that economic gains from trade would not become harmful to the environment as would be expected.

At the same line of research, there are two other main studies from Shafik and Bandyopadhyay (1992) and Panayotou (1993) which aims to find whereas the relationship between economic growth and environmental quality may change at some point towards country's development path.

Shafik and Bandyopadhyay (1992) took data from 149 countries between 1960 and 1990, with an analysis of 10 different environmental indicators. He used log-linear, log-quadratic, and log-cubic polynomial functional forms of GDP per capita to estimate the EKC. The turning point, in which it may change the sign from positive to negative, appears when a country reaches a level of income which people feel more comfortable to demand a cleaner environment and more efficient structure. The results showed that just two air pollutants confirm the behavior expected, the remaining indicators would not confirm the EKC hypothesis. These inconclusive results can be interpreted as signs of a complex relationship between growth and environment.

Panayotou (1993) applied four different environmental indicators with nominal GDP in order to estimates the EKC for the late 1980s. The analysis consisted of cross-sectional data estimation techniques with log-quadratic and translog functions. The author concluded that the EKC is valid for all the estimated curves. He proposes that decreases in environmental devastation might be possible with the support of higher levels of income because economic growth might have impressive power over environmental quality improvement, especially in developing countries.

Grossman and Krueger (1991), Shafik and Bandyopadhyay (1992) and Panayotou (1993) found the same indication that appears to have a relationship between per capita income and measurement level of environmental quality, and it has the U-inverted curve aspect. A hypothesized inverted-U relationship between environmental degradation and economic growth is called "Environmental Kuznets Curve", based on the analogy with the income-inequality relationship presuppose by Kuznets (1955).

The controversy of whether environmental degradation increases constantly, decreases constantly, or first increases and then declines onward a country's development path, has significant implications for policies. A constant increase in environmental degradation with economic growth demands more rigorous policies related to environmental regulations. It can even lead to putting limits on economic growth to guarantee a sustainable economic growth activity (Arrow et al. 1995). Constantly decrease environmental degradation towards a country's progress path implies that accelerate economic growth policies also drive to a fast-environmental improvement with no need for additional environmental policies. In fact, it might slow down economic growth and, consequently, decrease environmental improvements.

As illustrated in Figure 2 below, at low levels of development, both quantity and intensity of environmental degradation are limited to the impacts of subsistence economic activity. As industrialization increases, both resource depletion and waste generation accelerate (Panayotou, 2016). However, at higher levels of development, structural change towards information-based industries and services, increases the demand for environmental quality and more efficient technologies, which results in a decline of environmental degradation (Panayotou, 2016).

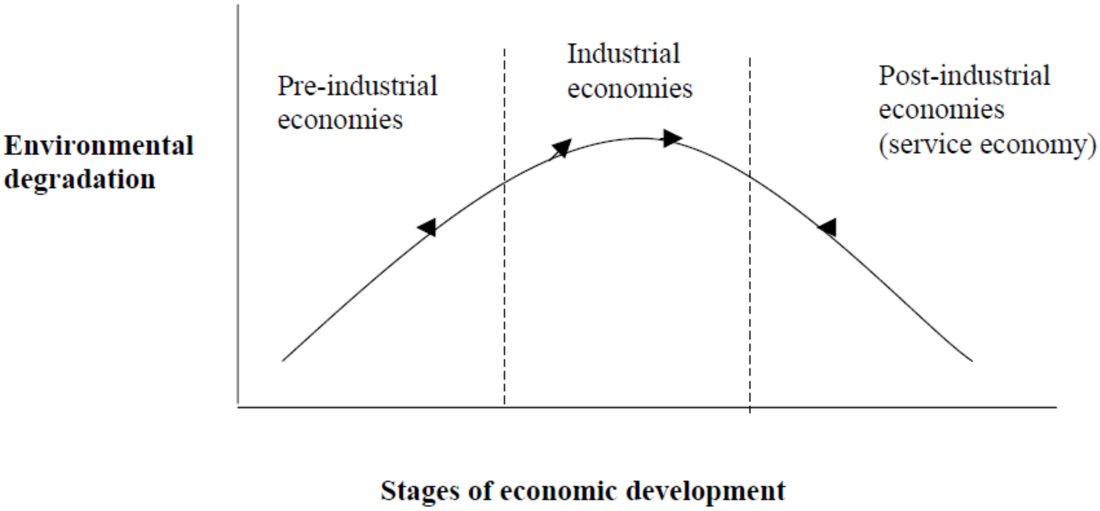


Figure 2: The Environmental Kuznets Curve (Panayotou, 2016)

The Environmental Kuznets Curve (EKC) has been used to clarify the relationship between economic activities and pollutant emissions, as well as the relationship between economic activities and the use of natural resources. The EKC hypothesis postulates that environmental degradation initially inflates when a country's per capita income is considered low, and over time, as the economy strengthens, environmental degradation decreases. This situation typically results in an inverted U-shaped relationship between income and the use of natural resources and/or pollution emissions.

Besides inverted U-shape, some studies show other behaviors for their empirical analyses, especially S-shaped curve [see, among others, Atici (2012); Zhang et al. (2011); Pérez-Suárez and López-Menéndez (2015)]. According to Friedl and Getzner (2002), the EKC hypothesis analysis typically considers three types of empirical specifications: linear, quadratic (inverted-U), and cubic specifications (N-shaped) or sideways-mirrored (S-shaped).

Atici (2012) investigates the relationship between trade liberalization and environment, in all ASEAN countries, with special reference to the trade flow with Japan. The results show that carbon emissions display an inverted S-shape for all groups, so this find could alert for some increase in emissions, depending on the country's location in the development path. This is because some of the countries from the developing group and the entire late-developing group are still near the starting point of the development process and income level has still not achieved a desirable level. Thus, the emissions level is expected to increase in the near future. In order to prevent the region from becoming a pollution haven, more strict regulations and cleaner technologies must be adopted in export-led sectors. It demonstrates the impact of understanding the interaction between development and GHG emissions in order to prevent environmental risks.

In fact, regarding the EKC hypothesis and if the hypothesis is confirmed by evidence, economic development will be favorable for the environment in the long run, although it may massively and irreversibly devastate the environment in the short-run (Özokcu and Özdemir, 2017).

Beckerman (1992) defends the idea that the condition of economic growth is important to get environmental improvement. The EKC hypothesis claims that economic growth is the solution for environmental degradation rather than a danger for the environment (Stern et al., 1996).

The presence of the EKC hypothesis has been confirmed in 70% of surveyed studies on East Asia and Pacific, Europe and Central Asia, Americas, Middle East and North Africa, South Asia, Sub-Saharan Africa, on emerging countries, and on countries in different regions including developed and developing economies (Al-Mulali et al., 2015).

In terms of empirical EKC studies, there is plenty of studies using different explanatory variables aside from GDP per capita, selecting many ranges of time periods and applying different geographical locations, as well as, adopting many types of econometric techniques such as cross-sectional, time series and panel data estimation in order to prove their hypothesis.

Also, there are some different explanations available in the literature for EKC shape, the most known is about people getting an enlarged sense of value in environmental amenities when a country reaches enough standards of living (Pezzey, 1992; Baldwin, 1995). According to Roca

(2003), when income hits a certain level, people are willing to pay for a cleaner and more efficient environment.

Other explanations were discussed by many authors such as Grossman and Kruger (1991), which says that environmental degradation tends to boost economic structure changes from agriculture to industry and from energy-intensive industry to services and knowledge-based technology industry. Komen et al. (1997) affirm that as a wealthy nation can afford to spend more on Research and Development, the obsolete technologies are replaced by cleaner technologies, which can, eventually, improve environmental quality. Following this point of view, political system and cultural values can play a crucial role in the implementation of more pro-environmental policies (Ng and Wang, 1993).

Another very significant aspect related to EKC is that, in its simplest form, it does not account for trade patterns which may partially explain the pollution reduction observed on high-income economies, with the opposite condition noticed on low-income economies. This situation is called the pollution haven hypothesis (PHH) and it potentially generates trade patterns.

The PHH claims that differences in environmental regulations thoroughness between developed countries and developing countries will provide the latter comparative advantage in pollution intensive production (Cole, 2004). Therefore, the developed countries may increase more cleaning production, on the other hand, the developing countries tend to rely on pollution intensive output. So, if the PHH remains, the EKC may not imply a net reduction in pollution, but it just transfers the pollution from developed to developing countries. In order to test this hypothesis, Cole (2004) estimates EKCs for 10 pollutants, regulating by the share of GDP in manufacturing, trade openness, and dirty trade flows. He finds shreds of evidence that trade openness and the proportion of dirty imports have an influence on emissions in developed countries, which contributes to supporting the PHH. However, he observes that the effect is relatively small when comparing to other emissions determinants. Also, for the most pollutants that he tested, he finds indications to support the EKC hypothesis.

Some papers such as Birdsall and Wheeler (1993) found that pollution intensity growth in developing countries was on its highest levels in periods that OECD environmental regulations were reinforced. Antweiler et al. (2001) studied the impact of trade liberalization on the city-level of sulfur dioxide concentrations and established some evidence of pollution haven pressures.

The most common dependent variable in the estimated models for empirically prove the EKC existence is CO_2 emission (e.g. Saidi and Hammami, 2015; Piłatowska et al., 2015; Farhani et al., 2014; Arouri et al., 2012; and Iwata et al., 2010). The EKC shape for CO_2 emissions is supported by Iwata et al. (2010); Saboori and Sulaiman (2013); Farhani et al. (2014); Piłatowska et al. (2015); and Sinha and Shahbaz (2018).

Another important point to discuss related to EKC researches is the variety of the empirical data used to achieve the existence of this curve. Recent literature on CO_2 and the EKC has concentrated on groups of countries, distinguished either by the level of income and development or by geographic proximity. For instance, Kearsley and Riddel (2010) and Beck and Joshi (2015) compared OECD and non-OECD countries, and some studies were specifically devoted to Middle-East and North-Africa countries (Farhani et al., 2014; Arouri et al., 2012) and the Asian continent (Apergis and Ozturk, 2015; Saboori and Sulaiman, 2013).

Baek (2015) says that when cross-sectional or panel data of a group of countries are selected in empirical models, an income effect with one country might interfere in the other countries analyzed, thereby, resulting in the existence (non-existence) of an EKC for a certain type of pollutant.

Early studies have generally embraced cross-sectional or panel data analyses in testing the EKC hypothesis (e.g., Panayotou, 1993; Roberts and Grimes, 1997; Harbaugh et al., 2002; Liu, 2005; Frankel and Rose, 2005). These studies provided mixed results, for example, Panayotou (1993) found empirical evidence of the EKC for SO_2 emissions in 50 developing and developed countries. Contrarily, Harbaugh et al. (2002), found that the EKC hypothesis for air pollutants are not applicable to 35 cities worldwide. According to Stern et al. (1996), an investigation of time-series data of single country could be a recommendable approach since it allows to consider specific historical experiences such as the development of trade relations, environmental policy, and exogenous shocks.

In order to address some aspects of aggregation bias, it is emerging literature that focuses on using time-series data at individual country levels such as Soytas and Sarin (2009); Jalil and Mahmud (2009); Iwata et al. (2010); Sugiawan and Managi (2016); Balaguer and Cantavella (2018); and Dong et al. (2018). Most of these studies took place in Western Europe, with very few studies in South America, more specifically Brazil and this is exactly what this work intends to do.

Very few studies have Brazil as their main subject, most publications in which Brazil is included, emphasis the comparison between country grouping such as Alam et al. (2016). In their studies, the data was taken from Brazil, China, Indonesia, and India; and they found that in the three first countries mentioned, CO_2 emissions decrease over time within income level increases. Authors such as Vehmas et al. (2003), Focacci (2005), Lenzen et al. (2006), Poudel et al. (2009), Onafowora and Owoye (2014), and others, also use data from some countries which included Brazil to prove their hypothesis. Among the very few studies using data just from Brazil to study the behavior of EKC, we were able to find Pao and Tsai (2011).

Pao and Tsai (2011) examined the dynamic relationships between pollutant emissions, energy consumption, and the output for Brazil from 1980 until 2007. Also, they applied the Grey prediction model (GM) to predict three variables from 2008 until 2013. The findings of the inverted U-shaped relationships of both emissions and income; energy consumption and income suggest that both environmental damage and energy consumption firstly increase with income, then stabilize, and finally, decline. In their studies, they recommend that Brazil adopt the dual strategy of increasing investment in energy infrastructure and intensify energy conservation policies in order to boost energy efficiency and reduce wastage of energy.

The pioneering study on decoupling of CO_2 emissions and economic growth applied to the specific case of Brazil is provided by Mendonça and Gutierez (2000). Brazil has some peculiarities on energy's composition and huge importance on GHG context emissions because of the Amazon rainforest. The country has also been subject to many studies such as Luukkanen and Kaivooja (2002). They found that, among other discoveries and comparisons to other nations, the trend on carbon intensity in Brazil is related to the variation on fuel composition, interfering on diversification of Brazilian energy mix towards cleaner sources.

The EKC hypothesis considering Amazon deforestation was verified in the studies of Gomes and Braga (2008) and Araujo et al. (2008) at the state level, and in the latter one, the main goal was to check the institutional aspects. The EKC has also been verified with municipality data by Caldas et al. (2003), Santos et al. (2008) and Prates (2008).

2.2. Brazil: territorial and economic contextualization

The Brazilian territory has an area of 8,514,876 km², which gives him the fifth place in the ranking of the largest area on the planet, behind only Russia, Canada, the United States, and China. Brazilian's large territorial area gives the country the denomination of “continental dimensions” (IBGE, 2014). The Legal Amazon corresponds to the area of the Amazon Development Superintendence (SUDAM) activity, which is delimited in Article 2 of Complementary Law no. 124 of January 3, 2007. The region is composed by the states of Acre, Amapá, Amazonas, Pará, Rondônia, Roraima, Tocantins, and Mato Grosso, as well as the municipalities of the State of Maranhão located to the west of the 44th Meridian. It has an approximate surface area of 5 217 423 km², corresponding to about 61% of the Brazilian territory (IBGE, 2014).

In the economic scenario, Brazil is a member of the BRIC. It is an acronym which is primarily used in Goldman Sach’s report, in 2003, to distinguish the fast-growing economies of Brazil, Russia, India, and China (Yuan, 2011). The analysts forecast that these four economies will be wealthier than the G6 economies (United Kingdom, Germany, Japan, United States, France, and Italy) by 2050 (Yuan, 2011). As a consequence of their astonishing economic growth (which is particularly noticed in China and India), BRIC has developed into an important player in the world’s economy.

During the financial crises in 2009, G6 economies grew by 4.5% (average), whereas Chinese and Indian economies showed values around 9.2% and 8.5% growth, respectively; Brazil and Russia’s economies grew by 0.3% and 7.8%, respectively, in the same year (World Bank, 2019). In the following year, G6 economies grew by 2.8% while BRIC economies grew by 8.2% on average (World Bank, 2019).

In 2011, with the South Africa entry, the BRICS reached its definitive composition, incorporating a country from the African continent. The five countries that composed the alliance were grouped by their similarities. However, separately, they have distinct characteristics related to economic, social, political and cultural aspects, mostly because of their different history, religion, and climate (Almeida, 2009). Also, Leonova et al. (2007) argued that each country has its own particularities concerns when comes to customers, industries, trends in growth, environmental and resource governance.

On the other hand, there are economic aspects that involve these countries that should not be disregarded. In summary, BRICS together account for 42% of the population, 23% of GDP, 30% of the territory and 18% of trade worldwide (World Bank, 2019).

In addition to its economic importance, the group will have a great influence on world politics. According to Amorim (2010), the BRICS, besides the accelerated economic growth, hold significant territorial extension, natural and energy resources in considerable diversity and quantity, and large technological development.

In 2014, in per capita terms, CO_2 emissions were equivalent to 38.0 tons considering the whole BRICS group, where this value was 2.6 tons for Brazil (World Bank, 2019).

Besides BRICS, Brazil is also a part of G20, the world's leading economic governance association. The Group of 20 was created in 1999 as a response to the financial crises in Mexico (1994), Asia (1997) and Russia (1998). The Group is composed by South Africa, Germany, Saudi Arabia, Argentina, Australia, Brazil, Canada, China, South Korea, United States, France, India, Indonesia, Italy, Japan, Mexico, United Kingdom, Russia, Turkey and European Union (Brazil, 2019b). In addition to the permanent members, the current presidency of Argentina, Spain, Chile, and the Netherlands, as well as Jamaica, representing the Caribbean Community (CARICOM); Rwanda, representing the African Union (AU); Senegal, representing the New Partnership for Africa's Development (NEPAD) and Singapore, representing the Association of Southeast Asian Nations (ASEAN) (Brazil, 2019b).

Together, the countries in this group represent 90% of world GDP, 80% of international trade and two-thirds of the world's population. For these reasons, the group has great collective political and economic power, with the capability of influencing the international agenda, promoting debates on the main global challenges and taking joint initiatives to promote inclusive economic growth and sustainable development (Brazil, 2019b).

Considering environmental aspects, there is a relevant circumstance related to carbon dioxide emission of Brazil and its contribution to this GHG emission worldwide. Brazil is on the 13th position in the ranking of the most world's CO_2 emissions which the firsts' position are held by China, the United States, and India. The Brazilian contribution was about 1.3% of the global emission in 2017 (Atlas, 2019).

However, Brazil is characterized to have comparatively low per capita energy-related GHG emissions, only 2.4 tons CO_2 emission per capita, in 2014, which compares to 5.0 tons for world average in the same year (World Bank, 2019).

Major emissions have been historically concentrated in agriculture, forestry, and other land use, associated with deforestation, cropping and livestock (La Rovere, 2018). Brazil detains abundant natural sources of renewable energies, such as wind and solar power, hydraulic energy, small hydroelectric plants, ethanol and biodiesel (Pereira et al., 2012). Brazil has a total of 160 GW in installed capacity, of which 77 percent is from renewable resources, mainly hydropower, the other sources are distributed for: natural gas and biomass account for 9 percent each and nuclear for nearly 2 percent (Brazil, 2019a).

Considering carbon dioxide emission evolution, Brazil is increasing the emissions over the years, following the global tendency. Figure 3 illustrates the global carbon emissions tendency, split by countries grouping, as well as, some of the major emitters of CO_2 (China and India). Figure 3 also shows that China and India accounted for 44.2% and 10.6%, respectively, for total CO_2 emissions considering the developing world, in 2016. Over the past decade, these two countries have collectively contributed 70.5% of increased emissions in the developing world and 83.7% of increased emissions worldwide (Jiang and Liu, 2019). So, they are considered to be in the major dioxide emission countries along with the United States.

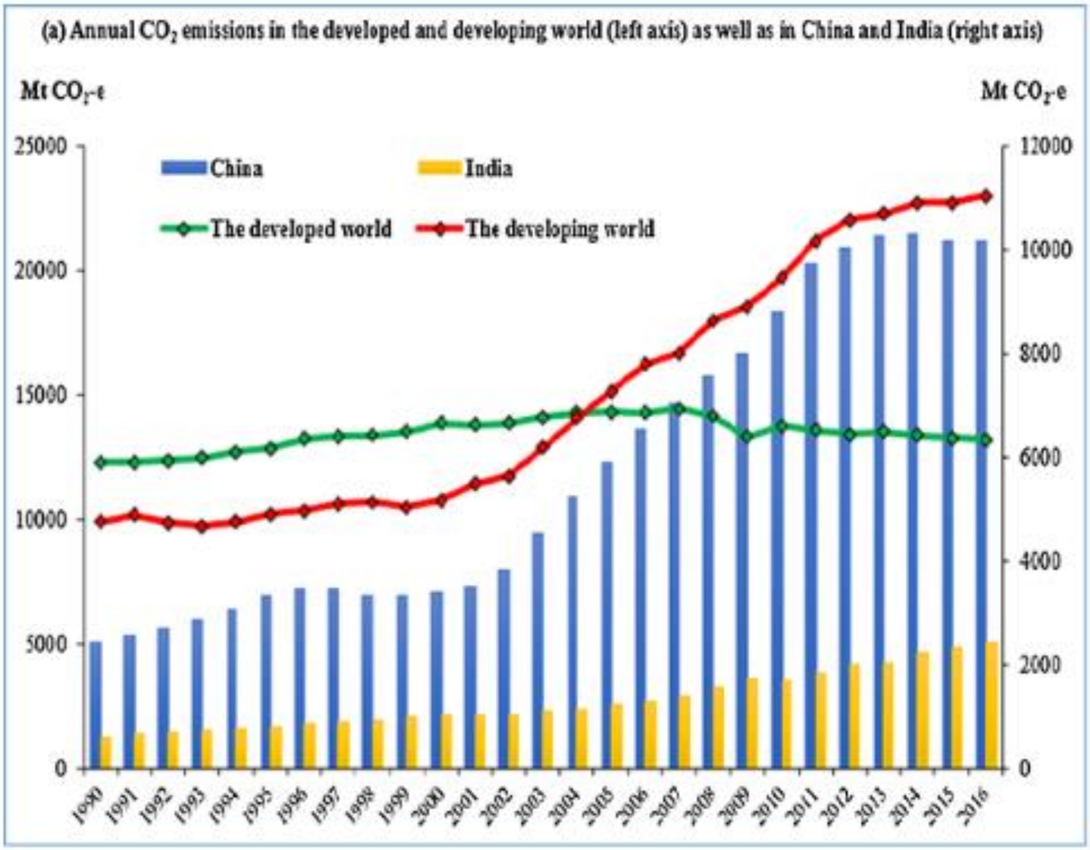


Figure 3: The dynamics and the share of CO2 emissions in the developed and developing world as well as in China and India (Jiang and Liu, 2019)

The Paris Agreement was entered into force on 4th November 2016 and became effective from 2020 when almost 105 Parties, responsible for more than 55% of total global Greenhouse Gas emissions, have deposited their instruments for the agreement acceptance (Oliveira et al., 2019).

In this context, Brazil was accountable for roughly 4–5% of global emissions between 1990 and 2014 (SEEG, 2016). Brazil has primarily committed to decreasing emissions during the Kyoto Protocol period by something between 36.1% and 38.9% by 2020, comparing to the emissions in 1990. The Nationally Determined Contribution (NDC) of Brazil, in the Paris Agreement, covered the greenhouse gas emissions decreasing by 37% and 43% of 2005 emissions levels, by 2025 and 2030 respectively (Oliveira et al., 2019).

Figure 4 shows the Brazilian's specific scenario for carbon dioxide emission over the years. In this figure, it is possible to see that Brazil is following the developing countries' tendency to increase CO_2 emissions through the years.

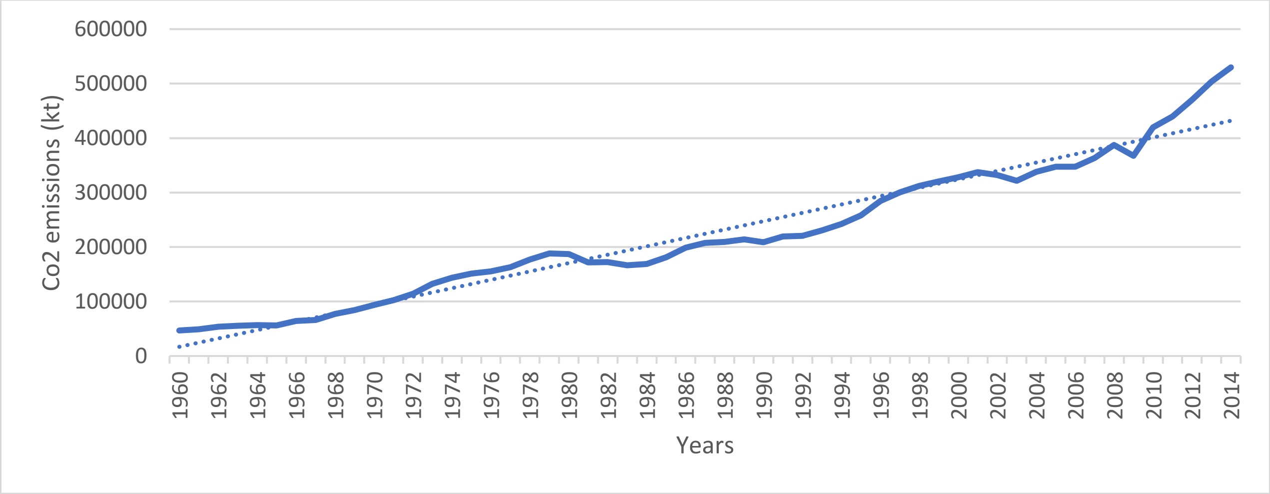


Figure 4: Carbon emissions evolution in kilotonnes (kt) for Brazil, 1960-2014
(World Bank, 2019)

Brazil is considered a forest country with about 58% of its territory covered by natural and planted forests, representing the second world's largest forest area in the world, trailing only Russia. On climate change point of view, deforestation of tropical forests stands out as an important element. According to Oliveira et al. (2011), deforestation in Brazil caused by hotspots makes the country a major world emitter of dioxide of carbon, one of the gases that cause the greenhouse effect. There is a concern that with the advance toward economic development, the pressure on tropical forests would increase.

The expansion of livestock, based on the policy of using natural resources, cause intensification on land use. These activities are, in general, related to fire utilization to clean the vegetation around. These actions result in high rates of deforestation Brazil, compounded by the fact that the frequency and the severity of such fires were intensified on dry years (1995, 1997, 1998, 1990, 2005, 2010, 2012, and 2015) (Artaxo et al., 2013; Van Der Werf et al., 2017; Ribeiro et al., 2018).

Deforestation fires in Amazonia are the main source of GHG in Brazil (SEEG, 2018). The current major concern of the country, considering the Amazon transformation, is the deforestation process because it may affect the rich local biodiversity and the environmental services provision, which is responsible to maintain part of global climate conditions. For those reasons, there is plenty of studies focus on this theme (Brazil, 2008).

Until the 1980s, the deforestation history in the Amazon Legal region was linked to government actions for the territory occupation and development by opening roads and encouraging migration (Ferreira and Salati, 2005). According to the Sustainable Amazon Plan, deforestation in the Legal Amazon region reached about 300 thousand km², equivalent to 6% of the total area until 1980. From 1980 to 2007, were deforested 432 thousand km², corresponding in total to almost 15% of the Amazon region (Brazil, 2008).

In the past decade, deforestation has slowed down remarkably, and in the Amazon, deforestation rates peaked at 2.8 Mha (million hectares) in 2004 but fell to 0.7 Mha in 2010 and 0.5 Mha in 2014 (La Rovere, 2018). Although, recent hotspots at Amazon in 2019 probably would change this scenario.

Battharai and Hammig (2001) explain, in general, low-income countries usually deforest areas without reposition, and, as income increases, investment for replacement compensates the deforested area. In addition, the economic structure and the energy demand standard change as income grows, reducing pressure on forests.

Brazilian’s electricity sector emissions raised 171% from 2011 to 2014, while the energy generation raised only 11% (de Lira Quaresma et al., 2018). According to the same authors, the government has created projects that focus on GHG’s mitigation, such as efficient energy use and *Plano Decenal de Expansão de Energia* (PDE -10 years Energy Expansion Plan), in order control the expansion of consumption without compromising life’s quality and economic development.

The Brazilian energy matrix is distinguished by a particular combination of fossil fuels and renewable energy sources. The main components of the Brazilian energy matrix are summarized in Table 1, according to the data supported by the Ministry of Mining and Energy through the

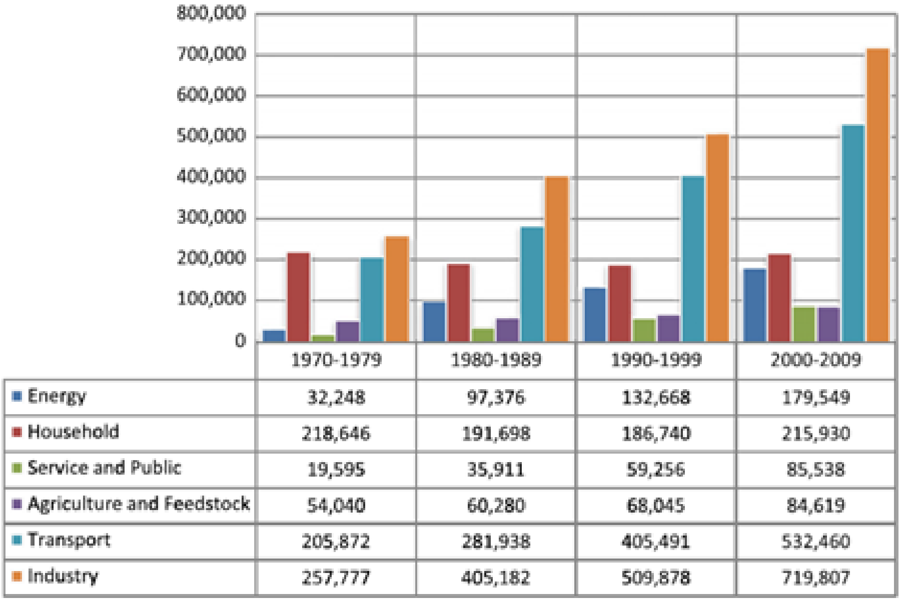
Brazilian Energy Research Company (EPE, 2010). In Table 1, it is possible to see a regular escalation of energy consumption in Brazil.

Table 1: Energy mix by source consumed in Brazil from 1970 to 2009

Sources	1970-1979	1980-1989	1990-1999	2000-2009
Oil Derivates	397,194 (48%)	509,288 (44%)	690,827 (47%)	856,777 (44%)
Biomass*	284,134 (35%)	255,202 (22%)	188,206 (13%)	209,436 (11%)
Sugarcane derivates	49,188 (6%)	144,041 (13%)	212,943 (14%)	295,708 (15%)
Hydropower	60,385 (7%)	142,367 (12%)	225,610 (15%)	318,119 (16%)
Other nonrenewable	27,815 (3%)	90,174 (8%)	135,345 (9%)	235,539 (12%)
Other renewables	2,971 (1%)	10,945 (1%)	21,629 (1%)	42,056 (2%)

Note: *Except sugarcane biomass; It is measure in toe that refers to tons of oil equivalent. Source: EPE, 2010.

During the period comprehend between 1970–2009, energy consumption rose 256.4% with emphasis on energy and industry sectors. In this period, energy production from hydropower and by products from sugarcane has an expressive growth. Figure 5 illustrates the total energy consumption in tons of oil equivalent by sector from 1970 until 2009.



	1970-1979	1980-1989	1990-1999	2000-2009
🟦 Energy	32,248	97,376	132,668	179,549
🟥 Household	218,646	191,698	186,740	215,930
🟩 Service and Public	19,595	35,911	59,256	85,538
🟪 Agriculture and Feedstock	54,040	60,280	68,045	84,619
🟦 Transport	205,872	281,938	405,491	532,460
🟧 Industry	257,777	405,182	509,878	719,807

Figure 5: Evolution of energy consumption by sector in Brazilian's economy (EPE, 2010)

It is possible to see, from Figure 5, that all sectors experienced increases in energy consumption, with exception of the household sector, which presented decreases in energy consumption in the period between 1980 and 1999. The reason for such a pattern is the exchange from conventional energy sources like firewood to more efficient sources such as liquefied petroleum gas (LPG) and electricity between 1984 and 1994 (EPE, 2010).

3. Methodology

3.1. Data: sources, description and analysis

In order to examine the empirical EKC analysis for Brazil, this paper uses annual data of Brazilian carbon dioxide emissions from 1960 until 2014, collected from Word Development Indicators compiled by the World Bank. From the same data source, the country's GDP per capita (measured in 2010 U.S. dollars) and imports of goods and services were gathered.

Carbon dioxide emissions are defined as stemming from the burning of fossil fuels and the manufacture of cement, including carbon dioxide produced during consumption of solid, liquid, gas fuels and gas flaring (World Bank, 2019).

GDP is the sum of gross value added by all resident producers in the economy plus any product taxes, minus any subsidies not included in the products' value (World Bank, 2019). Therefore, GDP per capita used in this analysis was the gross domestic product mentioned before divided by the midyear population. The data does not consider deductions for depreciation of fabricated assets or depletion and degradation of natural resources.

The imports of goods and services were used to create a variable called m, which indicates whether the country is imposing emissions to other countries. The formula used for this purpose was m equal to imports of goods and services (M), divided by the gross domestic product per capita (GDP).

$$m = \frac{M}{GDP} \qquad (1)$$

The variable *m* is imperative to test the pollution haven hypothesis. This hypothesis states that differences in environmental regulations between developed and developing countries may be one of the causes for developing countries specialized in the most pollution-intensive manufacturing sectors.

According to Cole (2004), the PHH provides further armament to those who declare that the EKC's inverted U-shape is barely caused by the developed countries exporting their pollution to the developing world.

In summary, the model comprehends three variables, the dependent one represents by the CO_2 emissions per capita (measured in metric tons) and two independent variables defined by GDP per capita and the calculated variable (m).

Brazilian carbon dioxide emissions grew consistently over the sample period, from 0.650 metric tons per capita in 1960 to 2.594 metric tons per capita in 2014, which corresponds to an average annual growth rate of 1.85%. In the last year analyzed, the total CO_2 emissions from Brazil were accounted for 83.871% of Latin America and Caribbean emissions. From the global spectrum, Brazil was responsible for 0.05% of CO2 emissions in 2014.

Brazil is one of the five major emerging economies with considerable participation in the world's greenhouse gas (GHG) emissions. In table 2, it is possible to visualize the average growth rate for Brazil, in five years date range, starting from 1960 until 2014. Also, the GDP per capita, the CO_2 emissions per capita and the variable *m* are shown in table 2 with the same date range.

Since 1960, Brazilian gross domestic product has increased at an average annual rate of 1.75%, reaching around 11.870,15 US dollars per capita in 2014. Even though the growth along these years has been not so expressive, it is still a considerable difference comparing to the previous value of 3.425,43 US dollars of GDP per capita in 1960. This trend reflects on the evolution of the Brazilian economy, which has been characterized by a sharping growth associated with an increase in energy demand and mobility.

However, our sample period is also characterized by an increase in both CO_2 emission and GDP per capita, which reached their peak on the last data analyzed (2014), at 2,6 metric tons of CO_2 emission per capita and 11.870,15 USD GDP per capita.

Table 2: Gross Domestic Product per capita, the variable *m* and CO_2 emissions

Date Range	Average Growth Rate (%)	GDP (USD)	CO_2 Emissions (metric ton)	M (%)
		per capita		
1960-1964	-	3,640.80	0.68	3.9
1965-1969	9.09	3,971.67	0.79	3.3
1970-1974	42.20	5,647.87	1.17	5.2
1975-1979	30.54	7,372.67	1.48	5.0
1980-1984	4.31	7,690.13	1.37	3.7
1985-1989	7.39	8,258.58	1.43	3.1
1990-1994	-2.89	8,020.23	1.45	4.8
1995-1999	7.48	8,620.19	1.76	8.2
2000-2004	3.72	8,940.55	1.84	7.3
2005-2009	13.41	10,139.45	1.90	8.9
2010-2014	14.89	11,648.78	2.35	12.4
Overall sample				
μ		7,987.05	1.45	0.05
se_μ		318.35	0.06	0.004
CV		0.30	0.33	0.60

Notes: μ, se_μ and CV stand for the mean, standard error and coefficient of variation respectively.
Source: Own Elaboration based in Data from World Bank (2019)

From Figure 6, we can see that between 1980 until 1994, the emission of CO_2 is almost constant, as well as the GDP, with just a few variations. This fact can be related to economic stagnation in Brazil during this period. The 80s and 90s are known as the lost decades when the Brazilian's entire territory was impacted by the productive restructuring of capitalism or neoliberal globalization (Maricato, 2015). In 1990, Fernando Collor de Mello's government initiated a series of free-market and neoliberal reforms that tried to mitigate, among other things, Brazil's technological backwardness caused by protectionism in the 1970s and 1980s. Although inflation was controlled at that point, social cuts and money shortages caused a political and social crisis that persisted after Collor's impeachment, in 1992.

His successor, Vice President Itamar Franco appointed Fernando Henrique Cardoso as Finance Minister, from 1993 to 1994, who developed the Real Plan. The Real Plan was a new economic plan that stabilized the economy for further economic liberalization, dollar parity, and budget balance. This new economic model has led to economic growth in Brazil, from 1994.

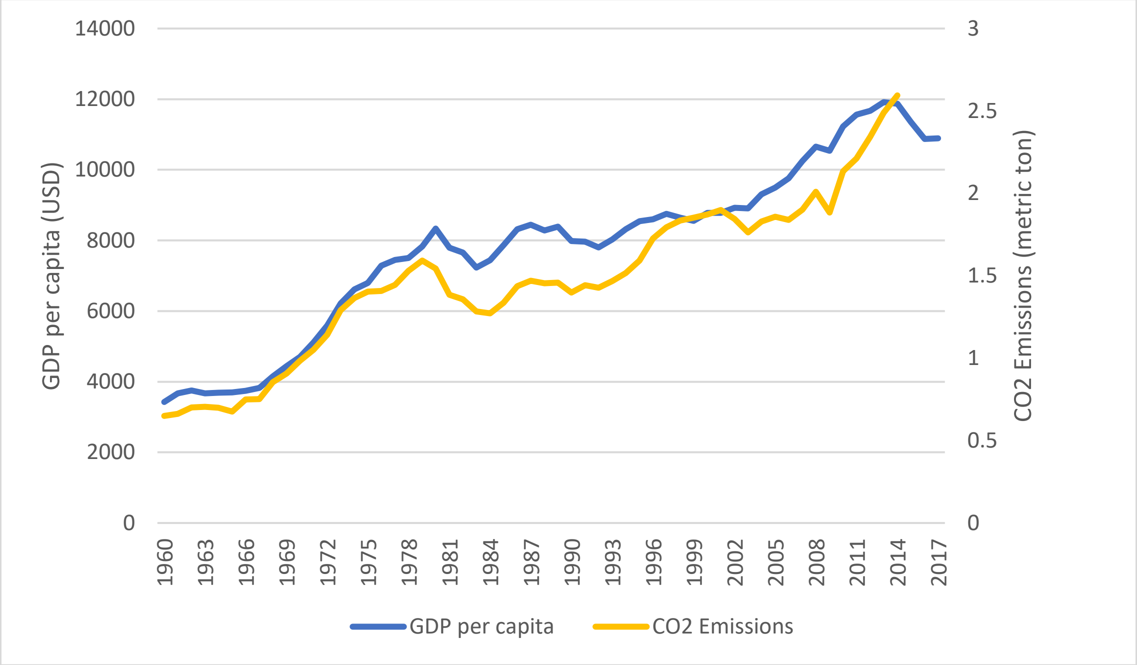


Figure 6: Evolution of CO_2 and GDP (1960-2017)
Own Elaboration based in Data from World Bank (2019)

The Pollution Haven Hypothesis states that differences in environmental regulations between developed and developing countries may be the cause of developing countries focus on most pollution-intensive manufacturing sectors, switching off with developed countries (Cole, 2004). According to the same author, if the PHH is legitimate, then omitting exports and imports from industries associated with high emissions levels (dirty industries) may bias the estimate of EKC's turning point. In our methodology, we also tested this hypothesis to verify whether Brazil is imposing emissions to other countries or not, based on its current importation pattern. For this test, we use variable *m*, which represents the proportion of imports of goods and services to GDP is for testing the pollution haven hypothesis.

3.2. The model

The first step towards this goal is finding a more accurate regression for this purpose. The data set used in this analysis was time-series dimension for annual CO_2 emission in per capita terms from 1960 until 2014.

We rely on the software STATA and Gretl to perform our calculations. We applied some regression models on the equation, such as linear, quadratic and cubic. A multinomial curve model is proposed with the variables mentioned before, in the following three modes:

a) A linear model in that environmental quality monotonically changes with economic growth;

$$CO2 = \alpha_0 + \alpha_1 x_t + \alpha_2 m_t + \varepsilon_t \qquad (2)$$

b) A quadratic function model in the forms of U-shaped or inverted U-shaped relationship between dioxide emissions and economic growth;

$$CO2 = \alpha_0 + \alpha_1 x_t + \alpha_2 {x_t}^2 + \alpha_3 m_t + \varepsilon_t \qquad (3)$$

c) A cubic function model in the forms of N-shaped or the inverted N-shaped relationship between dioxide emissions and economic growth;

$$CO2 = \alpha_0 + \alpha_1 x_t + \alpha_2 {x_t}^2 + \alpha_3 {x_t}^3 + \alpha_4 m_t + \varepsilon_t \qquad (4)$$

Where CO_2 is carbon dioxide emission per capita in Brazil; x_t is gross domestic product per capita for Brazil; m_t is the variable calculated based on the import of goods/services and gross domestic product. Lastly, ε_t is an error term.

We use the DOLS procedure (Stock and Watson, 1993) to fix autocorrelation problems. Besides, we use the Schwarz Bayesian information criterion (BIC) to determine the number of lags and leads need to include in the regressions in order to find the best specification for each model. These results are in the annex section.

3.3. Stationarity- Basic ADF tests (with and without beaks)

3.3.1. ADF without breaks

We begin our empirical work by performing the usual Augmented Dickey-Fuller (ADF) to test the null hypothesis of a unit root in all variables.

Table 3 displays the results of the ADF test for the variables in level, in logarithms, in first differences and in first differences of logarithms. For the level and logarithms, we found that the t-ADF statistics are all lower in absolute value than the critical values, with a confidence level of 95%. Therefore, we cannot reject the null hypothesis, and we concluded that all variables are non-stationary in both levels and log levels. On the other hand, for the first differences of both levels and logarithms, all the critical values are higher in absolute value than the critical value of 5% significance level, thus, the null hypothesis of unit root is rejected. We interpreted this as evidence that the series on first differences are stationary [that is, they are integrated of degree 1, [I (1)].

Table 3: ADF Results

	Variable	Deterministic Component	Lag	t-ADF	tc	P-Vaule	BIC
Level	**CO2**	None	0	3.77	-1.95	1	-129.79
	GDP	None	1	1.58	-1.95	0.97	791.42
	m	None	0	0.93	-1.95	0.90	-401.81
Log-level	**CO2**	Constant	0	-1.26	-2.93	0.64	-169.38
	GDP	None	1	1.88	-1.95	0.99	-215.53
	m	None	0	-1.06	-1.95	0.26	-86.80
1st Diff (level)	**CO2**	Constant	0	-5.63	-2.93	**0.00**	-124.97
	GDP	Constant	0	-5.09	-2.93	**0.00**	789.56
	m	None	0	-5.84	-1.95	**0.00**	-396.81
1st Differences (log-Level)	**CO2**	None	1	-2.63	-1.95	**0.01**	-163.99
	GDP	None	0	-4.01	-1.95	**0.00**	-216.00
	m	None	0	-5.57	-1.95	**0.00**	-89.67

3.3.2. ADF in the presence of possible breaks

The unit root literature shows that the existence of structural breaks can qualitatively affect the robustness and nature of the results of standard stationary tests. Hence, we consider the possibility of structural breaks in the time series affects their deterministic components. These results are in the annex section.

The importance of structural breaks for the implementation and interpretation of unit root tests was first emphasized by Perron (1989) and Rappoport and Reichlin (1989). Perron (1989) suggested that structural change in time series can influence the test results for unit roots. According to the same author, in the presence of a structural break, conventional testing procedures may erroneously fail to reject the null hypothesis, that the series is integrated of a higher order.

Table 4: ADF unit roots tests allowing for known break points

Variables		Break dates	Det	Lag	ADF-Statistic
Levels	**GDP**	1980	Constant and trend	1	-3.75
	CO2	1986	Constant	2	-3.12
	m	1975	Constant	0	-3.10
Log levels	**GDP**	1973	Trend	1	-4.50**
	CO2	1979	Constant and trend	2	-4.77
	m	1979	Constant and trend	1	-3.30
1st Diff (levels)	**GDP**	2003	Constant and trend	0	-5.79***
	CO2	1979	Constant	0	-6.94***
	m	2005	Constant and trend	0	-6.64***
1st Diff (log-levels)	**GDP**	1980	Constant	0	-5.48***
	CO2	1974	Constant and trend	0	-6.73***
	m	1985	Constant	0	-6.28***

Note: *, ** and *** stand for $0.10<p$, $0.01<p<0.05$ and $p<0.01$, respectively.

By visual inspection, it is possible to identify some years where structure breakdowns are likely to have occurred. We use the Chow test (Chow, 1960) to confirm the dates of the expected structural breaks. In particular, the Chow tests identified in the years of 1980-1983, 2007-2009, 2009-2010 as good candidates for breaks in terms of GDP, CO_2, and *m*, respectively.

Furthermore, we use the Zivot-Andrews (1992) to test the unit roots with one unknown breakpoint. Our results suggest that the null hypothesis of a unit root cannot be rejected for levels either for Logs, except for GDP with trend, at 5% level of significance. For the first differences in level and in log-level, all results suggest that the null hypothesis of a unit root can be rejected at 1% of confidence level (see table 4).

3.4. Cointegration

The next step consists in testing the existence of a long-run relationship between the CO_2 emissions and the exogenous variables, i.e., the gross domestic product and calculated variable *m*. For this purpose, we use two strategies. In the first approach, we apply two tests using the residuals of the cointegrating equation. First, we use the augmented Engle and Granger test (AEG) proposed by Engle and Granger (1987), in which the null hypothesis is the usual unit root in the residuals. Followed by the Shin test [Shin (1994)] in which the null hypothesis of cointegration is tested, like a typical Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test with appropriate critical values.

We begin with the AEG test, which is actually an ADF test that uses critical values adjusted to the number of variables in the cointegrating equation. In particular, the Mackinnon (1991) table is used to obtain the critical values for no constant, with constant, and constant and trend cases. Table 5 represents the Granger cointegration Test.

Table 5: Augmented Engle and Granger Cointegration Tests

Deterministic Component	Lags	t-Stat ADF	BIC
None	0	6.86***	-192.65
Constant	0	6.78***	-188.95
Constant and trend	3	6.70***	-185.27

Using Mackinnon (1991) for critical values.
Note: *, ** and *** stand for 0.10<p, 0.01<p<0.05 and p<0.01, respectively.

Then, we perform the Shin test. The critical values for the cointegration test are taken from the Shin Test Table (Marques, 1998, p.535-536). We elect number four as the number of regressors, with a confidence level of 95%, so the value obtained is 0,121. Table 6 shows the results of the

Shin (1994) test. Both the ADF test and the Shin test allow the conclusion that there is evidence of a long-run relationship.

A) Test Shin Results

Table 6: Test Shin Results

Variable	P-Value
Residual	4.20E-02
Resid_lag1	2.42E-02
Resid_lag2	3.19E-02
Resid_lag3	4.20E-02
Resid_lag4	5.77E-02
Resid_lag5	7.45E-02

The second approach is the Johansen procedure. When the cointegrating equation has more than two variables, the Engle and Granger (1987) method does not prevent the feasible existence of more than one cointegration relationship. Therefore, we may be estimating a linear combination of the various possible cointegration vectors.

To avoid it, we use a second strategy suggested by Johansen (1988), which applies the vector autoregression (VAR, hereafter) and a maximum likelihood estimator approach to estimate all feasible cointegrating vectors and, thus, test hypotheses on these vectors' coefficients. The optimal structure of the lags from VAR models is selected by picking the lowest value of the BIC indicator, with critical values provided by Osterwald-Lenum (1992).

Moreover, the use of the two strategies is justified by decreasing the chances of erroneous conclusions. Engle and Granger (1987) strategy suffers from bias which, for small samples and with annual data, tends to reject cointegration when it exists. On the other hand, the Johansen procedure (1988) favors predicting the existence of cointegration when it is not true.

B) Johansen's Cointegration Tests

Table 7: Johansen's Cointegration Tests

Eigenvalues	λ-Trace Test				λ-Max test			
	H_0	H_A	Statistic	Critical Value	H_0	H_A	Statistic	Critical Value
Model 1								
0.4702	$r = 0$	$r \geq 1$	45.55	34.07 *	$r = 0$	$r = 1$	34.31	28.14 *
0.1395	$r \leq 1$	$r = 2$	11.24	20.16	$r \leq 1$	$r = 2$	8.11	22.00
0.0563	$r \leq 2$	$r = 3$	3.13	9.14	$r \leq 2$	$r = 3$	3.13	15.67

Note: *Denotes rejection of the hypothesis at the 0.05 level.

Table 7 presents the results of Johansen's Cointegration Tests. The trace statistic for $r = 0$ is 45.547 and exceeds the critical value of 34.07, thus, the null hypothesis of no-cointegration must be rejected. In contrast, for $r \leq 1$, the trace statistic of 11.240 is lower than the critical value of 20.16, therefore, the null hypothesis is not rejected. We can, consequently, conclude that the variables are cointegrated and that there is only one cointegrating vector. The λ-Max test confirms these two results.

Summing up, our analysis suggests that there is significant evidence of a long-term relationship between CO_2 emissions per capita, GDP per capita and variable *m*.

4. Results and discussion

As said before, we use the Stock and Watson (1993) procedure that is also known as dynamic ordinary least squares, or DOLS for short, to estimate the following models of the function applied to Brazil. We perform linear, quadratic and cubic regressions. It is important to acknowledge that linear regression was the drive to apply the DOLS procedure in quadratic and cubic regressions. The regression results can be seen in Table 8.

Table 8: Regression Results

Parameters	**Linear US$**	**Quadratic US$**	**Cubic US$**
Constant	**1.45E-02**	**-4.19E-01****	**1.45****
Std Err	3.96E-02	1.76E-01	4.27E-01
GDPpp	**1.6E-04*****	**2.86E-04*****	**4.38E-04*****
Std Err	7.54E-06	4.5E-05	1.79E-04
GDPpp2		**-1.17E-08*****	**-8.00E-08*****
Std Err		3.04E-09	2.40E-08
GDPpp3			**3.60E-12*****
Std Err			1.04E-12
Variable m	**3.93**	**7.45*****	***5.15******
Std Err	6.19E-01	7.59E-01	6.16E-01
Adjusted r-squared	**0.97**	**0.97**	**0.99**
R-squared	0.97	0.98	0.99
F test: overall significance	833.22***	102.22***	266.76***
DW	**0.36**	**2.01**	**2.06**
BIC	**-106.51**	**-98.89**	**-139.57**

Note: *, ** and *** stands for 10%, 5% and 1%, respectively

Upon examining the results in greater detail, we find that all estimates are statistically significant at 1% level for the quadratic and cubic regressions (except for constant which has a 5% significant level in both models). The sign of the GDP parameter is mostly positive and the same happens to the variable *m*. These results can indicate a positive correlation between these variables.

The dependent variable, CO_2 emissions per capita, is explained by 97% and 99% of the independent variables, GDP per capita and variable *m*. This is because, R^2 had a value of 0.9691 and 0.9880 in the quadratic and the cubic model regression, respectively.

Per capita GDP presents a positive value, which means that this variable has a positive impact on the increase in per capita CO_2 emissions. CO_2 emissions will increase as income increases, but only to some extent. We observed that when the per capita GDP squared is used, it starts to receive a negative signal, in other words, at this point, the per capita GDP squared has a negative impact on the per capita CO_2 emission. Therefore, in the short run, it will assume the shape of an inverted U curve.

Also, per capita GDP was estimated at the cube to see if increases in income would continue indefinitely causing CO_2 emissions to fall. The positive result was a confident indication that further increases in income from a certain point would once again make CO_2 emissions rise again.

In the case of the variable *m*, we can see in table 8 that it shows a positive signal which means that an increase in this variable has a positive impact on the increase in CO_2 emissions. Remembering that variable *m* is equal to imports of goods and services, divided by the gross domestic product per capita. Hence, it indicated whether the country is enforcing emissions on other countries or not. Even though Brazil is considered as a developing county, we had this concern to test if it is imposing CO_2 emissions on other countries, which it buys goods and services. And, with our results, we can conclude that Brazil is not enforcing emissions to other countries.

In order to verify which part of the EKC curve Brazil is in, as well as, gather a basis to suggest some political implications related to the environment, we have done some calculations to encounter the extremes of the functions. First, we analyze the quadratic regression.

A quadratic relationship with opening downward direction, generally described as an inverted U-shaped curve, is the case of our quadratic regression based on the results from Table 8, in which $\alpha_1 \geq 0$; $\alpha_2 < 0$ and $\alpha_3 = 0$. This is a conventional Environmental Kuznets Curve. We can compute the turning points at $\mathrm{x}* = \frac{\alpha_1}{2\alpha_2}$ by setting derivatives of equation (2) equal to zero.

$$CO2 = -0.418677 + 0.0002856x - 1.17E^{-08}x^2 + 7.450654\, m + \varepsilon \qquad (5)$$

As a result, we find x*= 12205.13, that is the turning point for this function. In our sample period, we found the peak on the last data analyzed (2014) at 11.870,15 USD for GDP per capita. This means that we are almost in the turning point and it is going to take just a little time until the curve hits the turning point. In other words, we are almost to the point where environmental conditions would not be compromised by economic growth.

Secondly, we analyze the cubic regression. For this analysis, we consider the equation below with the results gathering from Table 8.

$$CO2 = 1.450706 + 0.0004376x - 8.00E^{-08}x^2 + 3.60E^{-12}x^3 + 7.450654m + \varepsilon \qquad (6)$$

A cubic polynomial is generally described as an N-shaped figure since $\alpha_1 \geq 0$; $\alpha_2 \leq 0$ and $\alpha_3 > 0$ (however, α_1 and α_2 cannot be 0 at the same time). From the equation above, we cannot obtain any turning point by setting the differential of the equation equals to zero. However, by setting the quadratic differential of this equation to zero, we can obtain a point at x*= 7.407,40. From the sign of the second derivative at the two sides of the curve, it is proved that the point is a turning point that happened in 1976 – 1977. And, the CO_2 emissions have been increasing with the growth of the economy. The relationship between CO_2 emissions per capita and GDP per capita is represented by a weak N-shaped curve among t. In Figure 7, it is possible to visualize this relationship.

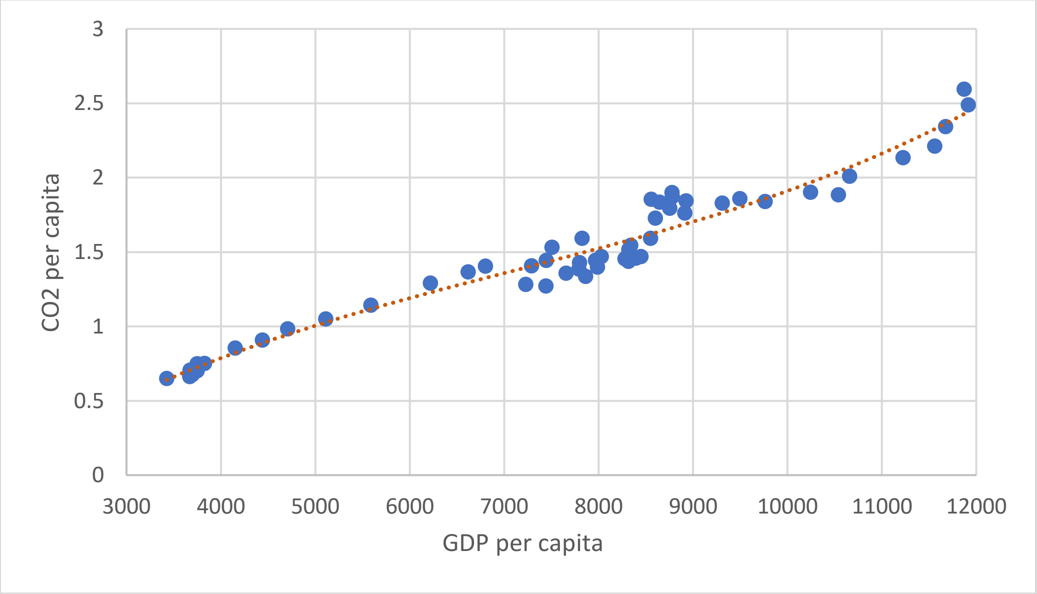


Figure 7: Relationship between CO2 emissions per capita and GDP per capita
Own Elaboration based in Data from World Bank (2019)

5. Limits of analysis and further extensions

In this paper, we present evidence of the effect of CO_2 emissions from burning fossil fuels and cement production on Brazilian gross domestic product per capita from 1960 to 2014. Using the DOLS procedure, our results point to the conclusion that CO_2 emissions have a direct effect on economic growth. At this point, reducing emissions can lead to decreasing economic growth, though, it is coming to the turning point where it would have a negative relationship. In other words, it is almost to the point where reducing emissions would not affect negatively Brazilian's economic growth.

The environmental policies of the local government play a crucial role in this scenario. In recent years, the local government has been exerting efforts to encourage cleaner production and to decrease the CO_2 emission. These actions are confirmed by agreements that Brazil has been signed along of the years. Brazil has primarily committed to decreasing emissions during the Kyoto Protocol period by something between 36.1% and 38.9% until 2020, comparing to emissions in 1990. The Nationally Determined Contribution (NDC) of Brazil, in the Paris Agreement, covered the greenhouse gas emissions decreasing by 37% and 43% of 2005 emissions levels, by 2025 and 2030 respectively (Oliveira et al., 2019).

Brazil is near to the point where the level of economic growth would lead to less carbon dioxide emissions. Because of the proximity to the turning point, we truly believe that the environmental condition would not compromise the economic growth of the country, in the near future.

In order to incentive this behavior, Brazil needs to continue applying environmental regulations and encourage the promotion of cleaner and more efficient technologies. It demonstrates the impact of understanding the interaction between development and GHG emissions to prevent some environmental risks.

According to (Özokcu and Özdemir, 2017), if the hypothesis of EKC is affirmed by evidence, economic development will be favorable for the environment in the long run, although, it may be massively and irreversibly devastating for the environment in the short run.

Countries, in general, have been concerned about the interactions between the environment and the economic growth, because they do not intend to compromise their growth, neither to deal with the consequences of environmental degradation. In other words, countries, in general, are constantly searching for ways to gather and maintain sustainable growth. In this way, the United Nations' Sustainable Development Goals (SDGs) were created attempting to integrate the three pillars of sustainable development (economic, environmental, and social) in 17 goals that simultaneously cover all the three aspects.

Sustainable development and its measurement are the keys to success in the United Nations' Sustainable Development Goals (SDGs). The ability to measure sustainable development enables us to understand the status of the world by checking progress in achieving sustainability. According to Biermann et al. (2017), integrating these aspects with their different agendas and actions in the implementation of the SDGs is a key challenge for decision-makers at all levels of governance.

This research is relevant since there are not many studies in this field applied to this specific country. Also, Brazil has some peculiarities that deserves much attention, such as the country's position and contribution to this GHG emission worldwide; Brazil is on 13th position on the ranking of the most world's CO_2 emissions which the contribution of 1.3% of the total global emission in 2017 (Atlas, 2019). Another aspect that makes Brazil a good case of study is related to the economy, Brazil is part of G20, the world's leading economic governance mechanism, and member of the BRICS, which represent a group of five major emerging countries (Brazil, Russia, India, China, and South Africa).

Another crucial and peculiar aspect about Brazil that needs special attention, it is about the Amazon rainforest, more specifically, the fact that most of the Amazon rainforest is in Brazilian territory. It has no implications for the sequestration capacity of the Brazilian total CO_2 emissions since Amazon rainforest sequesters all the carbon it emits. This fact contradicts the popular belief that Amazon is "the lung of the earth". However, the relevance of the Amazon rainforest cannot be neglected since it gives very important environmental services to Brazil and the Planet. The presence of the Amazon rainforest plays an important role in atmospheric circulation, which is closely related to climate change and the effect of its exploitation /extinction is particularly significant and the consequences are unknown.

Therefore, we reached our goal in this paper due to the non-rejection of our hypothesis that allows us to answer the proposed questions, especially: is it possible to integrate economic growth with the economy's decarbonization? If so, from which point? We find out that there is a robust relationship between CO_2 emissions and economic growth. Also, we tested the Pollution Haven Hypothesis and concluded that Brazil, according to commodity-importing countries, is not "exporting" environmental impacts on their suppliers.

Our work suggests three avenues for future research. Firstly, given that the branch of the curve on which the economy lies, the estimation of the environmental Kuznets curve using recent data is clearly a natural extension of this paper. Especially because of current huge burnings at the Amazon rainforest that occurred in 2019. Secondly, it would be interesting to analyze another country with similar economic characteristics to Brazil and compare the results evaluating the Brazilian peculiarities and their impacts on economics. Lastly, the Granger causality test would be a good extension of this research, because it can confirm if GDP is causing CO_2 emissions.

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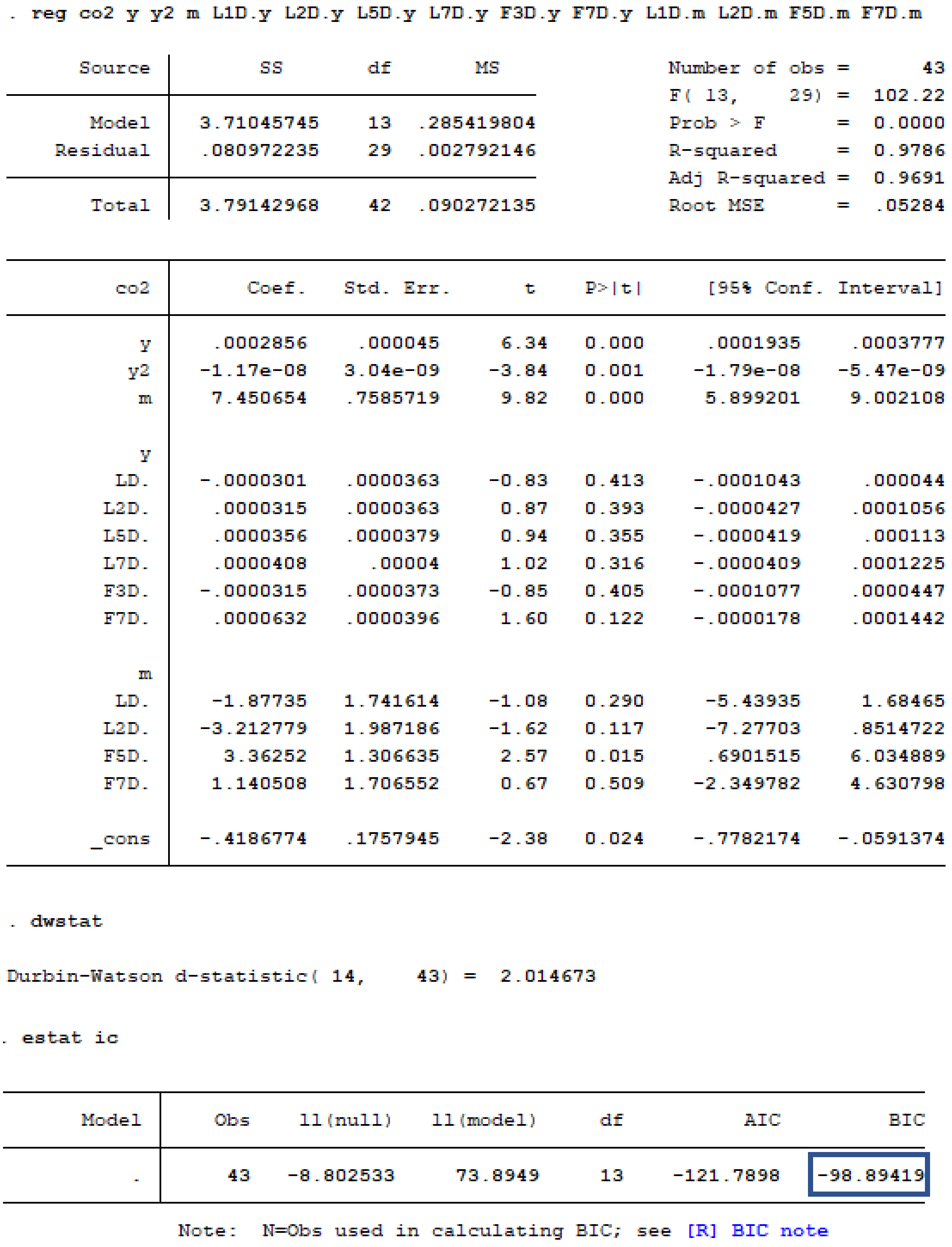
Annex

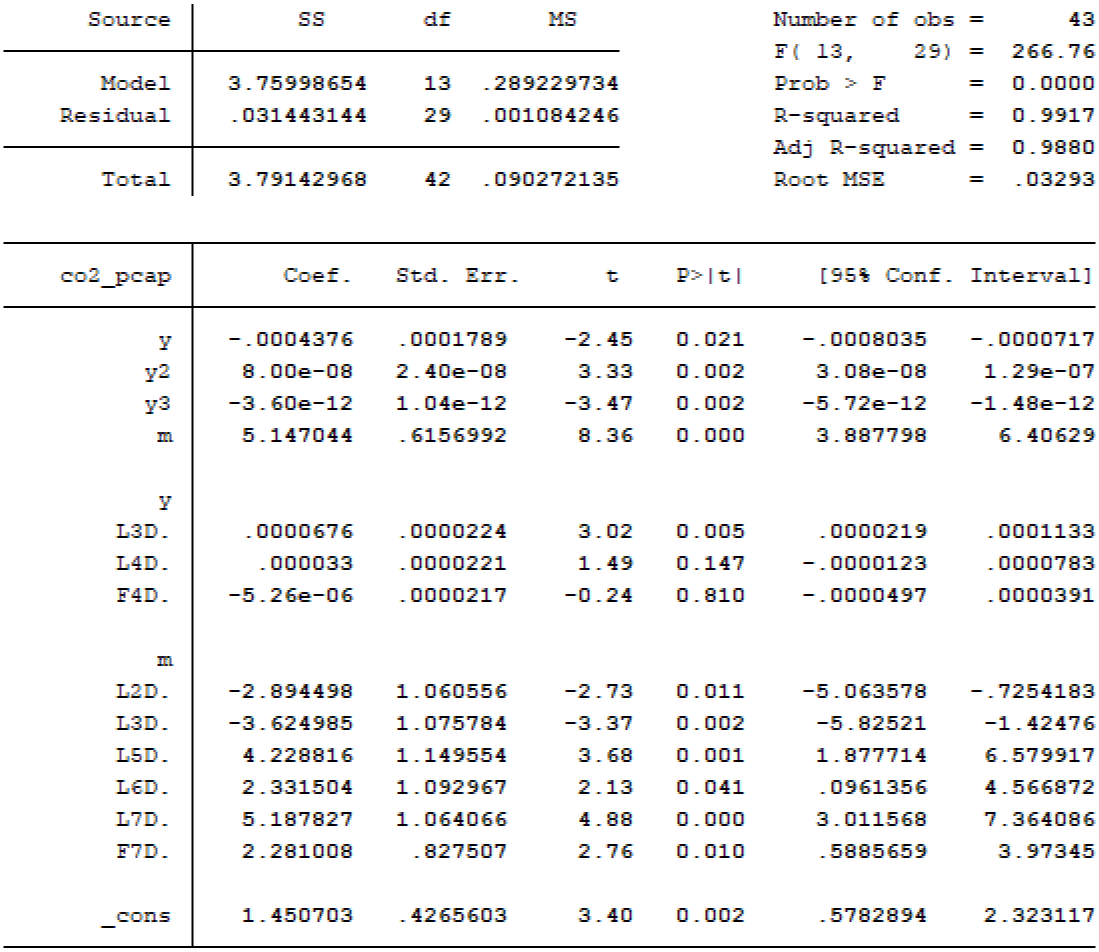
Regression Quadratic (DOLS):



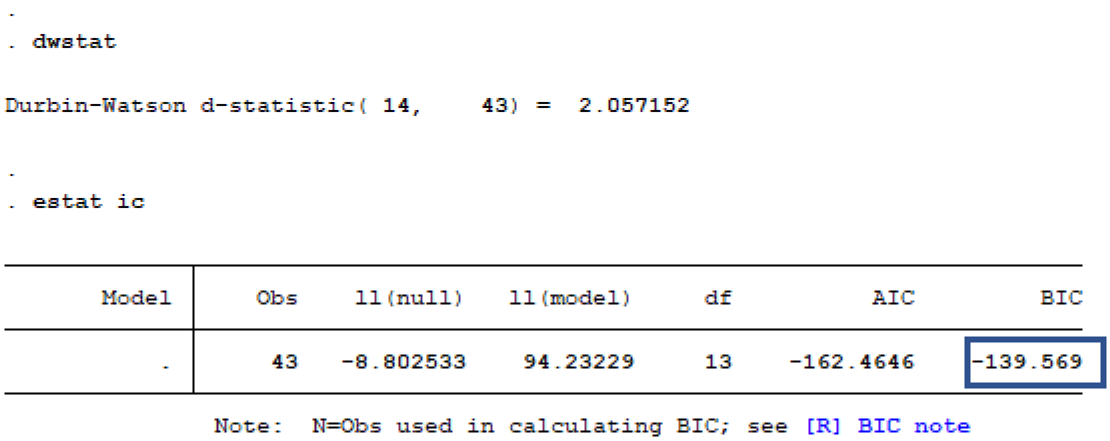
```
. reg co2 y y2 m L1D.y L2D.y L5D.y L7D.y F3D.y F7D.y L1D.m L2D.m F5D.m F7D.m

      Source |       SS       df       MS              Number of obs =      43
-------------+------------------------------           F( 13,    29) =  102.22
       Model |  3.71045745    13  .285419804           Prob > F      =  0.0000
    Residual |  .080972235    29  .002792146           R-squared     =  0.9786
-------------+------------------------------           Adj R-squared =  0.9691
       Total |  3.79142968    42  .090272135           Root MSE      =  .05284

------------------------------------------------------------------------------
         co2 |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
           y |   .0002856    .000045     6.34   0.000     .0001935    .0003777
          y2 |  -1.17e-08   3.04e-09    -3.84   0.001    -1.79e-08   -5.47e-09
           m |   7.450654   .7585719     9.82   0.000     5.899201    9.002108
             |
           y |
         LD. |  -.0000301   .0000363    -0.83   0.413    -.0001043     .000044
        L2D. |   .0000315   .0000363     0.87   0.393    -.0000427    .0001056
        L5D. |   .0000356   .0000379     0.94   0.355    -.0000419     .000113
        L7D. |   .0000408     .00004     1.02   0.316    -.0000409    .0001225
        F3D. |  -.0000315   .0000373    -0.85   0.405    -.0001077    .0000447
        F7D. |   .0000632   .0000396     1.60   0.122    -.0000178    .0001442
             |
           m |
         LD. |   -1.87735   1.741614    -1.08   0.290     -5.43935     1.68465
        L2D. |  -3.212779   1.987186    -1.62   0.117     -7.27703    .8514722
        F5D. |    3.36252   1.306635     2.57   0.015     .6901515    6.034889
        F7D. |   1.140508   1.706552     0.67   0.509    -2.349782    4.630798
             |
       _cons |  -.4186774   .1757945    -2.38   0.024    -.7782174   -.0591374
------------------------------------------------------------------------------

. dwstat

Durbin-Watson d-statistic( 14,    43) =  2.014673

. estat ic

-----------------------------------------------------------------------------
       Model |    Obs    ll(null)   ll(model)     df          AIC         BIC
-------------+---------------------------------------------------------------
           . |     43   -8.802533     73.8949     13    -121.7898   -98.89419
-----------------------------------------------------------------------------
               Note:  N=Obs used in calculating BIC; see [R] BIC note
```

Regression Cubic (DOLS):

reg co2 y y2 y3 m L3D.y L4D.y F4D.y L2D.m L3D.m L5D.m L6D.m L7D.m F7D.m



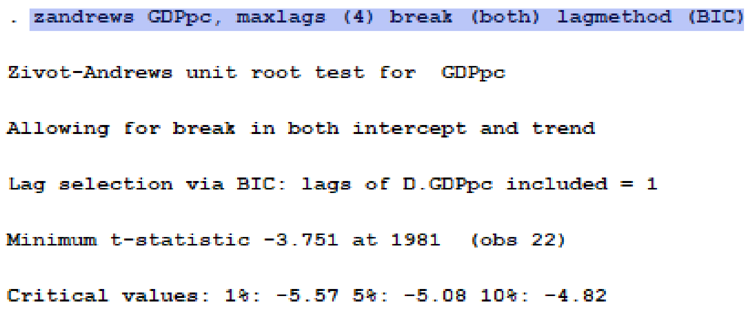
```
      Source |       SS       df       MS              Number of obs =      43
-------------+------------------------------           F( 13,    29) =  266.76
       Model |  3.75998654    13  .289229734           Prob > F      =  0.0000
    Residual |  .031443144    29  .001084246           R-squared     =  0.9917
-------------+------------------------------           Adj R-squared =  0.9880
       Total |  3.79142968    42  .090272135           Root MSE      =  .03293

------------------------------------------------------------------------------
    co2_pcap |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
           y |  -.0004376   .0001789    -2.45   0.021    -.0008035   -.0000717
          y2 |   8.00e-08   2.40e-08     3.33   0.002     3.08e-08    1.29e-07
          y3 |  -3.60e-12   1.04e-12    -3.47   0.002    -5.72e-12   -1.48e-12
           m |   5.147044   .6156992     8.36   0.000     3.887798     6.40629
             |
           y |
         L3D. |   .0000676   .0000224     3.02   0.005     .0000219    .0001133
         L4D. |    .000033   .0000221     1.49   0.147    -.0000123    .0000783
         F4D. |  -5.26e-06   .0000217    -0.24   0.810    -.0000497    .0000391
             |
           m |
         L2D. |  -2.894498   1.060556    -2.73   0.011    -5.063578   -.7254183
         L3D. |  -3.624985   1.075784    -3.37   0.002     -5.82521    -1.42476
         L5D. |   4.228816   1.149554     3.68   0.001     1.877714    6.579917
         L6D. |   2.331504   1.092967     2.13   0.041     .0961356    4.566872
         L7D. |   5.187827   1.064066     4.88   0.000     3.011568    7.364086
         F7D. |   2.281008    .827507     2.76   0.010     .5885659     3.97345
             |
       _cons |   1.450703   .4265603     3.40   0.002     .5782894    2.323117
------------------------------------------------------------------------------
```



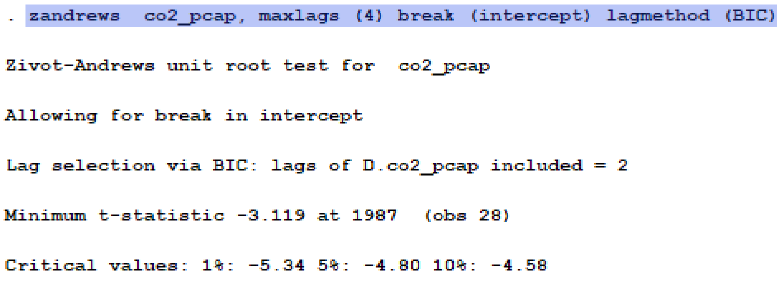
```
.
. dwstat

Durbin-Watson d-statistic( 14,    43) =  2.057152

.
. estat ic

-----------------------------------------------------------------------------
       Model |    Obs    ll(null)   ll(model)     df          AIC         BIC
-------------+---------------------------------------------------------------
           . |     43   -8.802533    94.23229     13    -162.4646    -139.569
-----------------------------------------------------------------------------
               Note:  N=Obs used in calculating BIC; see [R] BIC note
```

ADF in the presence of possible breaks:

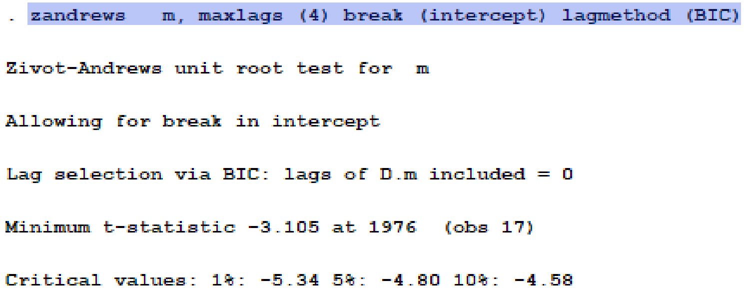
Levels:



```
. zandrews GDPpc, maxlags (4) break (both) lagmethod (BIC)

Zivot-Andrews unit root test for  GDPpc

Allowing for break in both intercept and trend

Lag selection via BIC: lags of D.GDPpc included = 1

Minimum t-statistic -3.751 at 1981  (obs 22)

Critical values: 1%: -5.57 5%: -5.08 10%: -4.82
```

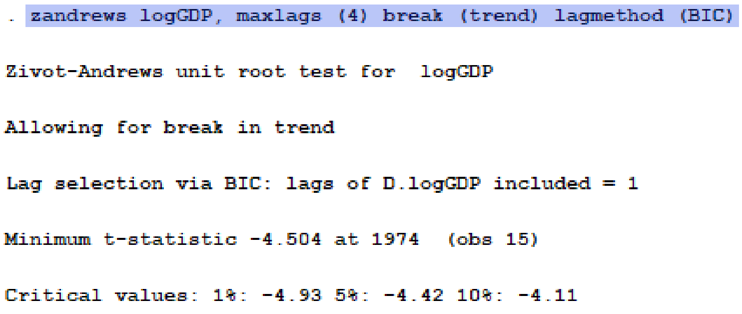


```
. zandrews  co2_pcap, maxlags (4) break (intercept) lagmethod (BIC)

Zivot-Andrews unit root test for  co2_pcap

Allowing for break in intercept

Lag selection via BIC: lags of D.co2_pcap included = 2

Minimum t-statistic -3.119 at 1987  (obs 28)

Critical values: 1%: -5.34 5%: -4.80 10%: -4.58
```

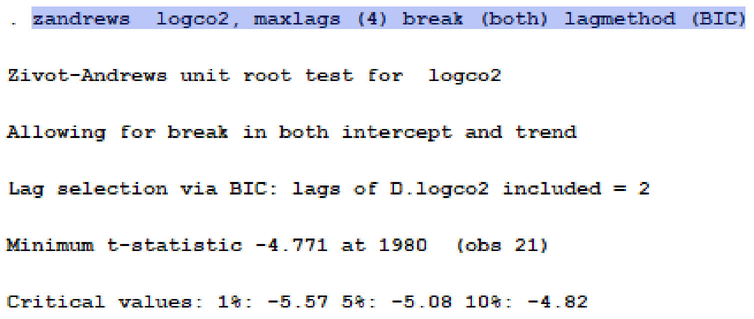


```
. zandrews   m, maxlags (4) break (intercept) lagmethod (BIC)

Zivot-Andrews unit root test for  m

Allowing for break in intercept

Lag selection via BIC: lags of D.m included = 0

Minimum t-statistic -3.105 at 1976  (obs 17)

Critical values: 1%: -5.34 5%: -4.80 10%: -4.58
```

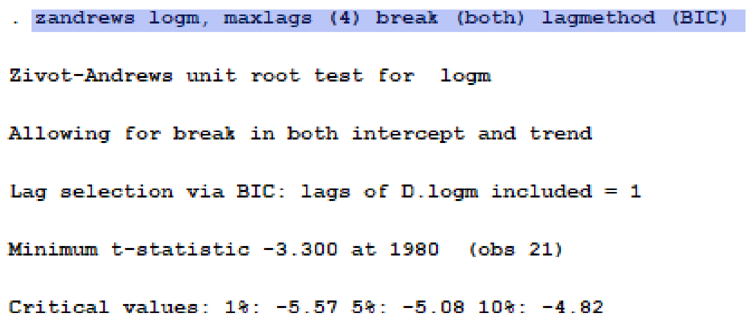
Logarithms:



```
. zandrews logGDP, maxlags (4) break (trend) lagmethod (BIC)

Zivot-Andrews unit root test for  logGDP

Allowing for break in trend

Lag selection via BIC: lags of D.logGDP included = 1

Minimum t-statistic -4.504 at 1974  (obs 15)

Critical values: 1%: -4.93 5%: -4.42 10%: -4.11
```

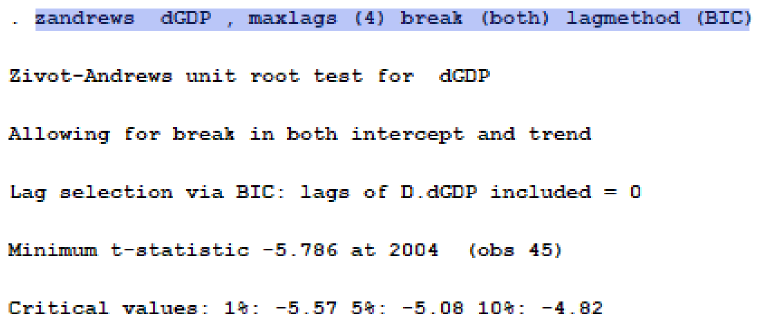


```
. zandrews  logco2, maxlags (4) break (both) lagmethod (BIC)

Zivot-Andrews unit root test for  logco2

Allowing for break in both intercept and trend

Lag selection via BIC: lags of D.logco2 included = 2

Minimum t-statistic -4.771 at 1980  (obs 21)

Critical values: 1%: -5.57 5%: -5.08 10%: -4.82
```

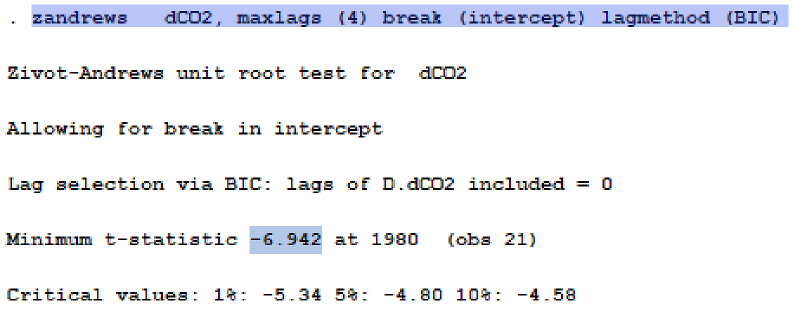


```
. zandrews logm, maxlags (4) break (both) lagmethod (BIC)

Zivot-Andrews unit root test for  logm

Allowing for break in both intercept and trend

Lag selection via BIC: lags of D.logm included = 1

Minimum t-statistic -3.300 at 1980  (obs 21)

Critical values: 1%: -5.57 5%: -5.08 10%: -4.82
```

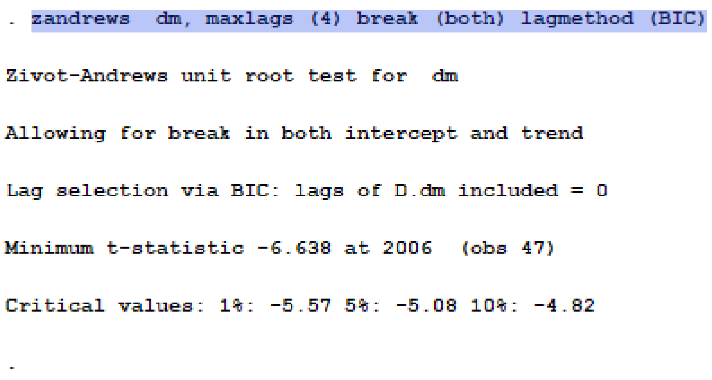
First Differences (in level):



```
. zandrews  dGDP , maxlags (4) break (both) lagmethod (BIC)

Zivot-Andrews unit root test for  dGDP

Allowing for break in both intercept and trend

Lag selection via BIC: lags of D.dGDP included = 0

Minimum t-statistic -5.786 at 2004  (obs 45)

Critical values: 1%: -5.57 5%: -5.08 10%: -4.82
```

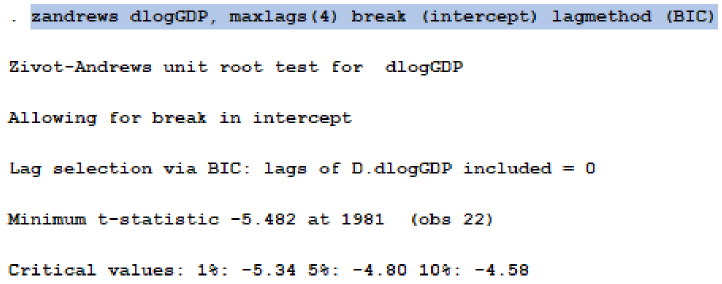


```
. zandrews   dCO2, maxlags (4) break (intercept) lagmethod (BIC)

Zivot-Andrews unit root test for  dCO2

Allowing for break in intercept

Lag selection via BIC: lags of D.dCO2 included = 0

Minimum t-statistic -6.942 at 1980  (obs 21)

Critical values: 1%: -5.34 5%: -4.80 10%: -4.58
```

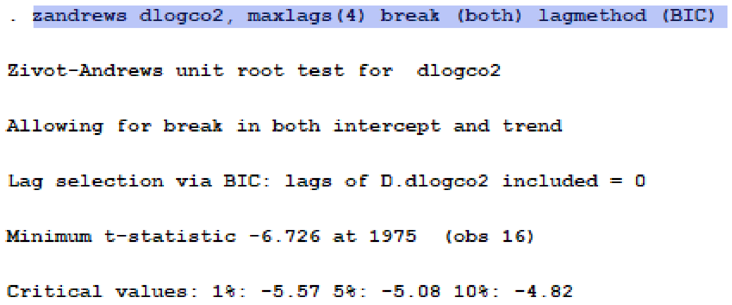


```
. zandrews  dm, maxlags (4) break (both) lagmethod (BIC)

Zivot-Andrews unit root test for  dm

Allowing for break in both intercept and trend

Lag selection via BIC: lags of D.dm included = 0

Minimum t-statistic -6.638 at 2006  (obs 47)

Critical values: 1%: -5.57 5%: -5.08 10%: -4.82

.
```

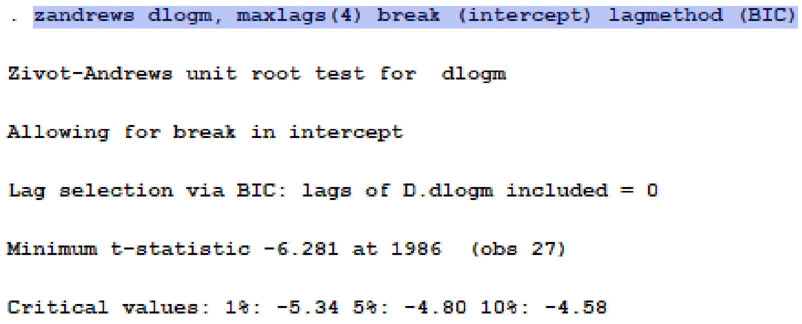
First Differences (in log):



```
. zandrews dlogGDP, maxlags(4) break (intercept) lagmethod (BIC)

Zivot-Andrews unit root test for  dlogGDP

Allowing for break in intercept

Lag selection via BIC: lags of D.dlogGDP included = 0

Minimum t-statistic -5.482 at 1981  (obs 22)

Critical values: 1%: -5.34 5%: -4.80 10%: -4.58
```



```
. zandrews dlogco2, maxlags(4) break (both) lagmethod (BIC)

Zivot-Andrews unit root test for  dlogco2

Allowing for break in both intercept and trend

Lag selection via BIC: lags of D.dlogco2 included = 0

Minimum t-statistic -6.726 at 1975  (obs 16)

Critical values: 1%: -5.57 5%: -5.08 10%: -4.82
```



```
. zandrews dlogm, maxlags(4) break (intercept) lagmethod (BIC)

Zivot-Andrews unit root test for  dlogm

Allowing for break in intercept

Lag selection via BIC: lags of D.dlogm included = 0

Minimum t-statistic -6.281 at 1986  (obs 27)

Critical values: 1%: -5.34 5%: -4.80 10%: -4.58
```