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"ESSAYS ON DECOUPLING ECONOMIC GROWTH AND ENVIRONMENTAL DAMAGE"

TESIS

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GENERAL INTRODUCTION

Economic growth is one of the factors that have led to the increase of greenhouse gas (GHG) emissions, and this relationship increases as more fossil fuels are burned for industrial purposes and as an energy source. It is also considered to have been the trigger for several global crises that we face today, among which we can include the crisis for food security (CGIAR, 2009), high levels of environmental degradation and loss of biodiversity (UNEP, 2011), climate change (Richardson et al., 2009) as well as other problems that have been caused in the name of development.

Economic development is an expression that may have a very different meaning to the concept of economic growth. Economists define the latter through magnitudes such as Gross Domestic Product (GDP) or National Income or Income (RN). When it is said that an economy develops, it usually indicates that it is economically evolving towards a better situation and, therefore, the term has a value component. The growth of the GDP or the RN does not necessarily imply more development and, conversely, the development could coexist with the impasse or even the decrease of these magnitudes.

Establishing that, it is imperative to confirm the assertion made by Costanza et al., (2014), when they affirm that economic growth has become the primary objective and that what had been essential ceased to be the satisfaction of human needs and became the accumulation of wealth, which generates a dynamic appropriation of natural resources. It is for this reason and with the aim of achieving the decoupling of economic growth from the increase in environmental damage, that the basic economies (which usually operate under a circular flow diagram, where only the existence of the consumer and the producer are recognized, and the environmental health is ignored or excluded as part of the economic process), must transition the traditional neoclassical economic model towards a more inclusive model with the environment and with the social sector.

The term *decoupling* has been used in environmental studies to characterize the relationship between economic activity and the degradation of the environment (Zhang, 2000). However, this has not been the first proposed concept to describe the effort that economies have made to achieve economic growth causing the least damage to the environment. Various concepts such as: immaterialization, qualitative growth, structural change, dematerialization, simple technical development and decarbonization (Janicke, 1988, De Bruyn et al., 1998, Hinterberger and Schmidt-Bleek, 1999, Tapio, 2002), have been used to study and describe the relationship between environmental damage and economic growth, taking particular interest in the relationship arising from the increase in Gross Domestic Product (GDP) and Greenhouse Gas (GHG) emissions.

The decoupling of GDP-GHG has also been studied under various parametric methodologies which have used processes of decomposition of identities or formulas (Yamaji et al., 1991, Zhang, 2000), measures of elasticity change (Tapio, 2002, Sun, 2005), the use of the environmental Kuznets curve (EKC) (Grossman and Krueger, 1995, Lapinskienė et al., 2014) and the evaluation of the existing correlation using diverse panel data methodologies (Nasir and Rehman, 2011, Alam et al., 2016). And even non-parametric alternatives have been used, such as the Data Envelopment Analysis (DEA) which is based on the productivity theory to measure the efficiency of a cluster of observations (Schuschny, 2007, Lozano and Gutierrez, 2008).

As previously specified, the need to transition traditional economies into economic models that are more respectful of the environment is essential and should be one of the primary objectives of both developed and developing economies, in order to achieve full welfare of the communities that conform them. Sustainable economy, green economy, low-carbon or hypocarbonic economy and ecological macroeconomics are some of the economic models proposed to include environmental degradation as part of the system (Warning and Assessment, 2011, EU-Commission, 2010, Rezai, 2016).

However, this transition of economic systems should be based on the application of environmental policies or strategies appropriate to the current situation of the economies, for this reason the identification of the main factors that increase emissions and environmental damage is essential.

Globally, economic growth and population growth have been the most important factors in the increase of CO_2 emissions from the burning of fossil fuels. The growth of the population between 2000 and 2010 remained more or less identical to the previous three decades, on the other hand, economic growth has increased considerably. (IPPC, 2014). However, these two factors are not the only instances that have caused the excessive increase of CO_2 in the atmosphere. Technological changes, institutional frameworks, lifestyle and international trade are some other factors that influence the amount of GHG emitted by a country.

One of the main methods used for the identification and analysis of the main factors for the increase in emissions is the so-called Kaya Identity, illustrated by Yamaji et al., (1991) which considers the economic, demographic and technological factors of a country.

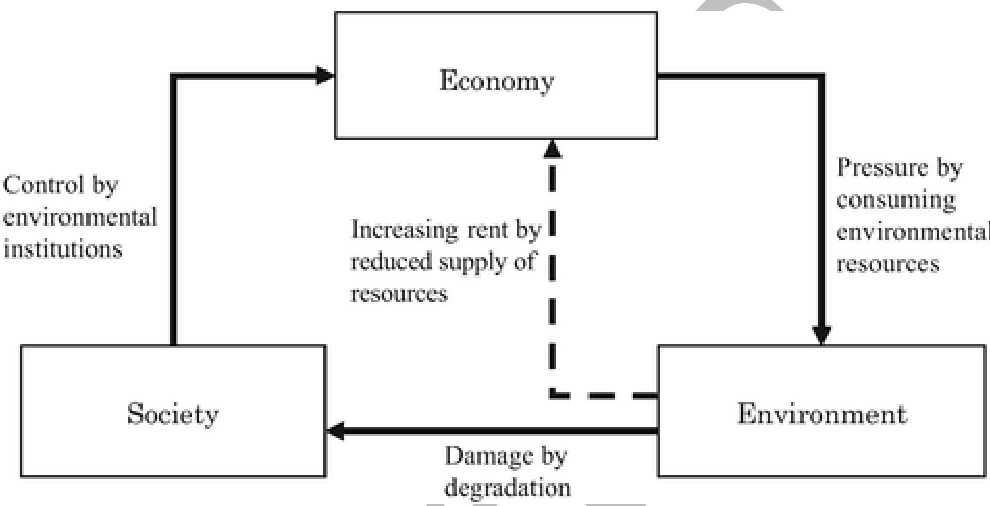
With all the above, it can be deduced that the problem of environmental quality would be a by-product of development, where a list of so many variables can not only be factors of the increase of emissions, but they can also play an important role in the reduction of pollutants if they are well redirected.

For example, Panayotou (1997) showed the importance of institutional systems and government policies on environmental matters, specifying that these variables can significantly reduce environmental degradation even with low income levels and they can also accelerate improvements to higher levels of income, which can be used to promote environmental improvements.

According to Acemoglu *et.al* (2005), institutional systems serve as a basis for economic development, since they give the actors involved the power and mechanisms necessary to condition the distribution of resources within the economy. So, when economic growth degrades the environment, actors in society, such as people suffering from the degradation, demand countermeasures of the economy, and the intuitional systems are obliged to intervene

(Okuma, 2017) as shown in Figure 0.1. However, environmental problems tend to be uncertain, in that regard, Weisbuch (2000) establishes the need to restructure or create new institutions that do not lack sufficient mechanisms to combat such problems.

Figure 0.1
Mechanisms of institutional coordination between economy and the environment



Source: (Okuma, 2017)

Establishing all of the above, this research aims to study the decoupling GDP-GHG and the various economic, technological, sociodemographic and institutional factors that cause effects on environmental degradation in countries with high incomes as well as in countries with low incomes, to be able to make a comprehensive analysis of the decoupling situation.

This thesis is composed of three chapters, which contain studies in the form of a research article, which have been submitted for publication. At the end of the document, the general conclusions of the work are presented.

Chapter 1 analyzes the degree of decoupling between economic growth and CO_2 emissions, using the method proposed by Tapio (2005) and by a graphical observation of the decoupling trend of five of the largest Latin American economies (Brazil, Mexico, Argentina, Colombia and Venezuela) which supposedly have high levels of emissions in comparison to the rest of the Latin American countries, for the study data from the period 1990-2014 is used. Additionally, the disaggregated factors of the Kaya Identity are analyzed to know the level of influence of the primary factors that increase the CO_2 emissions of the five countries under study from 1990 to 2014. The main results obtained with the decoupling elasticity analysis and the decoupling trend path observation show that Mexico and Venezuela experienced strong decoupling states in different periods, but Brazil, Argentina and Colombia did not present strong decoupling states in any of the study periods. While the results obtained from the Kaya disaggregated test suggest that the main primary factors that influence the amount of CO_2 emitted in Mexico, Brazil and Venezuela are due to the inefficiency of energy use. Meanwhile, economic growth is the second main factor for the increase in CO_2 emissions and is the main factor in Argentina and Colombia.

The second chapter, proposes the application of non-parametric models of Data Envelopment Analysis (DEA) to analyze population growth (P) and economic growth (measured in GDP) as two of the main pollution factors in the 28 member countries of the European Union, using data from 1995, 2000, 2005, 2010 and 2014. The DEA models proposed in this paper attempt to measure inefficiency indexes using data series of population and GDP as inputs and GHG emissions and energy efficiency as outputs of environmental damage. This approach is also used to analyze the decoupling situation between GDP and GHG emissions and the efficiency effect of the population structure. The results obtained show that there is a large gap to cover to meet the environmental goals set by the European Strategy 20-20, but in the last study period (2014) Luxembourg, Austria, Denmark, Malta, United Kingdom and Italy are the countries that could be considered the most decoupled of the European Union. Regarding the analysis of the population as one of the main inputs of environmental degradation, the least decoupled in 2014 were: Malta, Croatia, Latvia, Romania and Hungary.

Chapter 3 aims to study the decoupling effect from the validation of the environmental Kuznets curve (EKC), where decoupling will begin to be noticeable when the relationship between GDP and CO_2 emissions form a non-linear relationship similar to an inverted "U" (Grossman and Krueger, 1995). Additionally, this chapter focuses on recognizing that institutional systems serve as possible key factors to reduce CO_2 emissions. This work is an extension article of diverse investigations, considering then, that variables such as democracy, corruption perception, regulatory quality and political stability are the possible institutions that have the greatest incidence in reducing the level of CO_2 emissions in 8 Latin American countries (Argentina, Brazil, Chile, Colombia, Costa Rica, Mexico, Panama and Uruguay), which are the economies that generate the highest GDP per capita in Latin America and could be considered as the countries that cause the greatest environmental damage in the region, during the period 2007-2014. A model of Generalized Method of Moments panel data (GMM) is used to study the variables (CO_2 emissions per capita, GDP per capita, democratic index, corruption perceptions index, regulatory quality index and the index of political stability) to analyze the non-linear relationship that the EKC hypothesis assumes. According to the results obtained, three of the four institutional variables analyzed in this study turned out to be statistically significant (democracy, corruption perception and regulatory quality) showing marginal effects greater than the increase in GDP per capita, indicating an improvement in institutional systems in Latin America would tend to reduce CO_2 emissions in a greater proportion.

Research question:

Is it possible that decoupling GDP-CO_2 can occur in a world oriented toward economic growth?

Thesis hypothesis:

The decoupling of GDP and CO_2 emissions can happen if the economies have sufficiently high incomes with which they can take measures to counteract the environmental damage.

Overall objective:

Apply different methodologies to evaluate the decoupling effect in both countries with high income and in countries with low incomes, to estimate the use of this as an auxiliary tool for the creation of policies and specific actions aimed at the reduction of greenhouse gases.

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CHAPTER I.

Disaggregation of primary CO2 emission factors and decoupling states in five Latin American countries.

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CHAPTER I. Disaggregation of primary CO_2 emission factors and decoupling states in five Latin American countries.

Tania Muñoz-Ramos*

I.1Abstract

The aim of this study is to evaluate the decoupling states of CO2 emissions from Gross Domestic Product (GDP) in five Latin American countries (Brazil, Mexico, Argentina, Colombia and Venezuela) for the period of 1990 to 2014 by using a graphic chart of the decoupling trend and the analysis of the decoupling elasticity proposed by Tapio (2005), and the identification of the primary driving forces of CO2 emissions by disaggregating the Kaya Identity. Throughout the 24 years examined, the countries spread out into many different states of decoupling and the main primary driving forces behind the increase of CO_2 emissions are the energy inefficiency rate and the growth of GDP per capita. Mexico and Venezuela were the only countries that presented a *strong decoupling* state in the final period of the study (2010-2014). In order to accomplish the goals of the Paris Agreement, the countries in the study, especially those which did not present a strong decoupling state, need a rapid implementation of polices and several environmental strategies such as the reconstruction of the energy system towards clean energy.

Keywords: Economic growth, CO2 emissions, Greenhouse emissions, Decoupling, Decoupling elasticity, Kaya Identity,
JEL Classification: Q56

I.2 INTRODUCTION

Over the past two decades, global concern about the threat of global warming and climate change has grown rapidly. The Kyoto Protocol (1997) had as its main objective the reduction of greenhouse gases that cause climate change, since then, countries around the world began to implement action measures to mitigate and reduce greenhouse gases, mainly those that came from burning fossil fuels.

Numerous factors can influence the amount of emissions that are deposited into the atmosphere, such as economic factors, demographic development, technological changes, institutional frameworks, lifestyle and international trade (Duro and Padilla, 2006). But economic growth is one of the main reasons that have led to the increase of greenhouse gas emissions and its relationship increases as more fossil fuels are burned for industrial purposes and as an energy source.

In order to achieve the goal set by the Paris Agreement to reduce atmospheric temperature by 2°C, 188 countries committed themselves to encouraging, developing and applying environmental policies and actions with the goals of developing renewable technologies and improving energy efficiency and sustainable forest management (United Nations, 2015). However, developing economies should adopt better measures to reduce their CO_2 emissions since according to the Center of Global Development (2015),, as a whole, developing countries generate 63% of the total annual emissions.

To establish the policies that a country can carry out to reach the objectives described above, the quantitative degree of the decoupling status of greenhouse gas emissions and the country's Gross Domestic Product must be known in order to mitigate environmental problems. Furthermore, studies which analyze the main factors that influence the amount of emissions in a country are useful tools to determine which sector needs to modify or adopt certain public policies or environmental actions in order to reduce their emissions.

Therefore, the objective of this research is to analyze the degree of decoupling between economic growth and CO_2 emissions, using the method proposed by Tapio (2005) and by graphical observation of the decoupling trend of five of the largest Latin American economies (Brazil, Mexico, Argentina, Colombia and Venezuela) which supposedly have high levels of emissions in comparison to the rest of the Latin American countries, for the study data from the period 1990-2014 will be used. Additionally, the disaggregated factors of the Kaya Identity will be analyzed to know the level of influence of the primary factors that increase the CO_2 emissions of the five countries under study from 1990 to 2014.

This study is presented in different sections; the following one presents a brief review of previous studies that carried out research on the same subject, the third section explains in detail the methods and data used for the empirical study of this research, the fourth section presents the results of this research with a brief discussion of the findings. At the end of the document the conclusions of the work are presented.

The main results obtained with the decoupling elasticity analysis and the decoupling trend path observation show that Mexico and Venezuela experienced *strong decoupling* states in different periods, but Brazil, Argentina and Colombia did not present strong decoupling states in any of the study periods. While the results obtained from the Kaya disaggregated test suggest that the main primary factors that influence the amount of CO_2 emitted in Mexico, Brazil and Venezuela are due to the inefficiency of energy use. Meanwhile, economic growth is the second main factor for the increase in CO_2 emissions and is the main factor in Argentina and Colombia.

I.3 LITERATURE REVIEW

Economic growth has become the primary objective of every country, the essential ceased to be the satisfaction of human needs and became the accumulation of wealth, which generates a dynamic of appropriation of natural resources (Costanza et al., 2014). However, in the seventies the ecological problems gained strength and according to Naredo (2002), these problems shifted to more pragmatic aspects and related to economic management, forcing administrations with competencies in this field, to respond on the topic. Then concepts emerged such as ecological communities, green economies or sustainable economies. Terms that have as a target decoupling environmental damage from economic growth.

The term decoupling is used in environmental studies to fairly characterize the relationship between economic activity and the degradation of the environment. Zhang (2000), adjusted the term of decoupling to environmental studies and later this same term was adapted as an indicator of the Organization for Economic Cooperation and Development (OECD, 2002). However, this has not been the first proposed concept to describe the effort that economies have made to achieve economic growth causing the least damage to the environment, several terms have been used such as: decarbonization, de-linkage, immaterialization, qualitative growth, structural change, ecological efficiency and simple technical development (De Bruyn et al., 1998, De Bruyn, 2002, Hinterberger and Schmidt-Bleek, 1999, Janicke, 1988, Tapio, 2002).

According to Vavrek and Chovancova (2016), the relationship between economic growth and the situation of the environment has been broadly studied since the second half of the last century and the research approaches have been applied to several sectors in different regions and using different methodologies. For example, in 2001 the environmental Kuznets curve (EKC) was used to introduce the term environmental poverty to refer to the lack of a healthy environment for the development and survival of society (Liu, 2011). Tapio (2005) studies the relationship between GDP, traffic volume and CO_2 emissions from transport in 15 countries of the European Union and also analyzes the special case of road traffic in Finland between 1970 and 2001. In 2012, the effects of the link between CO_2 emissions and industrial electricity in Taiwan were concentrated in a basic economic model using input-output analysis (Lin et al., 2012). Ren and Hu (2012) presented a theoretical framework for decoupling which they used to calculate the trend of the decoupling effects of the non-ferrous metals industry in China. In 2015, the state of decoupling of CO_2 emissions and South African GDP from 1990 to 2012 was evaluated, where two methods were used for the decoupling analysis, the Tapio (2005) method and the method proposed by the OECD (Lin et al., 2015)

The study of the main primary factors that influence the behavior of greenhouse gas emissions is a very useful tool to develop or promote public policies or environmental strategies. One of the main methods used for this type of analysis is the Identity of Kaya, illustrated by Yamaji et al., (1991). In numerous studies the Identity of Kaya has been used to determine the degree of influence of population, energy, economic factors, etc., on the amount of emissions emitted per unit of Gross Domestic Product. In 2006, a methodology was developed for disaggregating the factors that intervene in the international inequality of per capita emissions, using the Identity of Kaya (Duro and Padilla, 2006). Xiangzhao and Ji (2008) modified the mathematical formula of the Identity of Kaya so that residues from CO_2 emissions were not counted, and the method was applied to an economic analysis of the trend of CO_2 emissions of China during the 1971-2005 period. In 2013, the Kaya Identity modification was used to analyze Ireland's primary emission factors from 1990 to 2010 (O'Mahony, 2013). Ren et al., (2014) analyzed the impacts of CO2 emissions from China's manufacturing industry during the 1996-2019 period through a logarithmic average currency index (LMDI) based on the modification of the Kaya Identity.

In Latin American countries, studies on the decoupling of economic growth of CO_2 emissions and the analysis of the primary factors that influence the amount of CO_2 emitted by a country are scarce. De Freitas and Kaneko (2011) reported that in Brazil from 2004 to 2009 there were several periods with states of relative decoupling and it was also determined that the main primary factors that influence the amount of CO_2 emitted are the energy intensity and the energy combination, the results of this research were obtained through the analysis of the logarithmic average currency index. Robalino-López et al., (2015) analyzed the possible changes of the main primary CO_2 emission factors in Venezuela for the 1980-2025 period using an extended methodology of the Kaya Identity and a hypothetical Kuznets curve method.

I.4 METHODOLOGY AND DATA

To fulfill the purposes of this research, the methodology proposed by Tapio (2005) was used to analyze the level of decoupling of economic growth with respect to CO_2 emissions, additionally graphs are used to show the decoupling trend for each of the countries in this study. The Identity of Kaya was also used as a means of identifying the main factors that determine the level of impact of human activities on the amount of greenhouse gas emissions.

These methods were used to study five of the largest economies in Latin America (Brazil, Mexico, Argentina, Colombia and Venezuela), in the period 1990-2014, which was divided into 6 sections for analysis (1990-1994, 1994-1998, 1998-2002, 2002-2006, 2006-2010, 2010-2014.).

The data used was obtained from the online database of the International Energy Agency (IEA, 2018). The amount of greenhouse gas emissions is expressed only through the data of CO_2 emissions measured in mega tons (Mt) emitted solely by the burning of fossil fuels. The GDP values are expressed in billions of dollars (USD, 2010). The data used on the total amount of energy supply (TPES) do not consider import values.

I.4.1 Decoupling analysis

This analysis of decoupling GDP-CO_2 describes the increasing or decreasing relationship of the study components. This relationship can be measured as the elasticity obtained through the percentage change rate of CO_2 emissions and the percentage change of GDP in a given time (Tapio, 2005), as shown in the following formula:

$$e = \frac{\%\,\Delta CO_2}{\%\,\Delta GDP} \quad (1)$$

Where *e* represents elastic decoupling; % ΔCO_2 expresses the change in the percentage rate of CO_2 emissions and % ΔGDP represents the percentage change of the Gross Domestic Product. %ΔCO_2 and %ΔPIB are obtained by formulas (2) and (3) respectively, where *t* represents the years.

$$\%\Delta CO_2 = (CO_2)_t - (CO_2)_{t-1} \,/\, (CO_2)_{t-1} \quad (2)$$

$$\%\Delta GDP = (GDP)_t - (GDP)_{t-1} \,/\, (GDP)_{t-1} \quad (3)$$

According to Tapio (2005), eight logical decoupling possibilities can be distinguished (Table 1.1) from the elastic values obtained with formula (1) instead of only the three decoupling states: coupled, decoupled or negative decoupling, as had been proposed by Vehmas et al., (2003).

Table 1.1. Decoupling states according to Tapio (2005**).**

Decoupling elasticity values	**Decoupling states**
$0.8 > e < 0$, increase of %GDP and %CO_2	Weak Decoupling
$e < 0$, increase of %GDP and decrease of %CO_2	Strong Decoupling
$e > 1.2$, decrease of %GDP and %CO_2	Recessive Decoupling
$e > 1.2$, increase of %GDP and %CO_2	Expansive Negative Decoupling
$e < 0$, decrease of %GDP and increase of %CO_2	Strong Negative Decoupling
$0.8 > e < 0$, decrease of %GDP and %CO_2	Weak Negative Decoupling
$1.2 > e < 0.8$, increase of %GDP and %CO_2	Expansive Coupling
$1.2 > e < 0.8$, decrease of %GDP and %CO_2	Recessive Coupling

Source: own elaboration based on Tapio (2005).

Tapio (2005), specifies that it is necessary to take into account small variations of the elasticity and in addition it must be considered that the increase of the study variables can be positive or negative. Thus, if the elastic value is between 0 and 0.8, it is considered that there is a *weak decoupling* when GDP and CO_2 increase. Elastic values below 0 demonstrate a *strong decoupling* status when GDP increases and CO_2 emissions decrease. When elastic values are greater than 1.2 and the GDP and CO_2 emissions decrease, it is considered that there is a *recessive decoupling*. Jointly, the negative decoupling includes three subcategories: *expansive negative decoupling*, in which the value of the elasticity is greater than 1.2 and both variables (GDP, CO_2) increase; *strong negative decoupling*, which happens when elastic values are less than 0 with an increase of CO_2 emissions and a decrease of GDP; *weak negative decoupling*, which occurs when the elastic values obtained are between 0 and 0.8 and when both variables decrease. At the same time the coupling state has two subcategories: *expansive coupling*, which happens when both variables increase, and the elastic value is between 0.8 and 1.2, while *recessive coupling* happens when the GDP and CO_2 emissions decrease.

Additionally, a graphic diagram of the decoupling trend was developed with the data obtained from the IEA database for each of the countries under study. Because the CO_2 and GDP variables do not share the same units, it was necessary to use a secondary axis to show the percentage increase in CO_2 emissions.

I.4.2 Kaya Identity Method

The Identity of Kaya is a model used to quantify the behavior of CO_2 emissions that was proposed by Yoichi Kaya in 1989. It is established as the product of various economic, political and demographic factors to assess CO_2 emissions from human activities (Xiangzhao and Ji, 2008). However, for this research the disaggregated form of the mathematical formula (4) applied to obtain the Identity of Kaya was used to be able to evaluate separately the level of correspondence of the factors with respect to the CO_2 emissions, for each of the 5 Latin American countries under study during the periods 1990-1994, 1994-1998, 1998-2002, 2002-2006, 2006-2010, 2010-2014.

$$CO_2 = \left(\frac{CO_2}{TPES}\right) x \left(\frac{TPES}{TFC}\right) x \left(\frac{TFC}{GDP}\right) x \left(\frac{GDP}{P}\right) x\ P \qquad (4)$$

In the previous formula, CO_2 is equal to the amount of CO_2 emissions, (CO_2 / TPES) expresses the amount of CO_2 emissions per unit of total primary energy supply (TPES), which depends on emission factors and fuel combinations. (TPES/TFC) is the total primary energy supply by total final consumption (TFC), which depends on the efficient conversion of energy and the combination of fuels. (TFC /GDP) is the amount of final energy consumed per unit of GDP, which depends on the final use of energy intensity. (GDP/ P) is the Gross Domestic Product divided by population (P) and depends on the combination of fuels, the activity and the structure of the economy of each country.

As the analysis of the Kaya method was carried out by periods, the formula (4) was modified to consider the percentage changes between periods, resulting in:

$$KI_d = (\%\Delta CO_2)\ x\ \%\Delta\left(\frac{CO_2}{TPES}\right) x\ \%\Delta\left(\frac{TPES}{TFC}\right) x\ \%\Delta\left(\frac{CO_2}{GDP}\right) x\ \%\Delta\left(\frac{GDP}{P}\right)\ x\ \%\Delta P \qquad (5)$$

In order to compare the results of this identity in the same way as the decoupling results, it was necessary to include the relationship (CO_2/ GDP) as part of the equation.

I.5 RESULTS AND DISCUSSION

The results of this research were broken down into the following sections by country, which include the results of the application of the Tapio (2005) method and the identification of the disaggregated factors of the mathematical formula of the Kaya Identity, as well as the comparison of the results of these two methods.

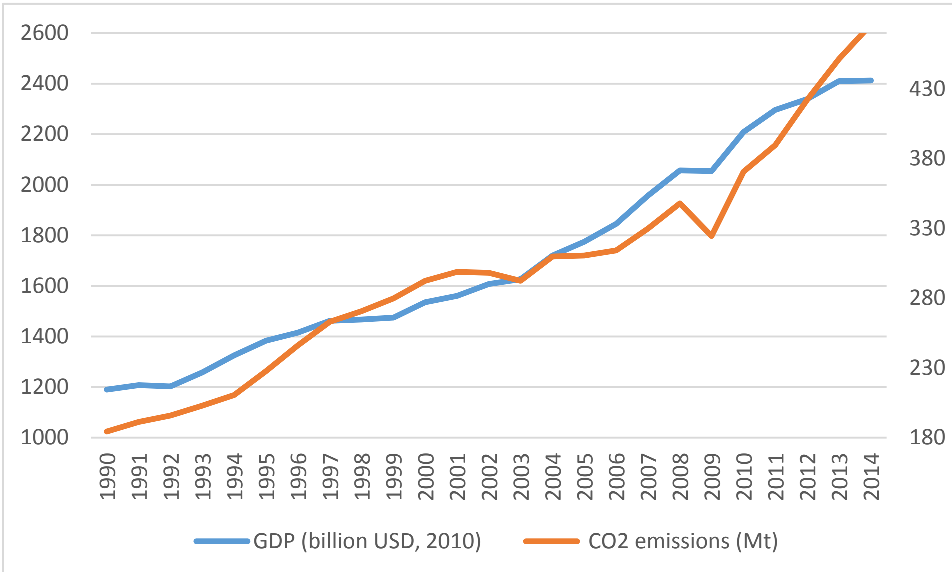
Brazil

Decoupling Analysis

The results obtained with the Tapio (2005) method show that during the entire study period (1990-2014) Brazil experienced weak negative decoupling, with percentage increases in GDP and CO_2 emissions. During the 2002-2006 period, a *weak decoupling* state was experienced because it presented an elastic value between 0 and 1.8, while GDP and CO_2 increased. The results of the decoupling status of the six study periods are presented in Table 2.

Figure I shows the decoupling trend of the country from 1990 to 2014, for which it was necessary to adjust the values of the variables in two axes. It is observable that the economic growth of this country increased and that the behavior of CO_2 emissions also tended to increase, which confirms that it has not been possible to reach the state of strong decoupling. With the help of this graph, the behavior of the GDP-CO_2 ratio is easily analyzed and is compatible with the results obtained from the annual elasticities of 1990 to 2014 in Brazil.

Figure I.1. Trend behavior of GDP and CO2 emissions in Brazil



Source: own elaboration based on the data of GDP (billions USD, 2010) and CO_2 emissions (Mt) reported by the IEA (2017) for Brazil.

The analysis of the annual data shows that in 2001 the highest *negative expansive decoupling* state was presented with an elastic value of 1.35. Meanwhile, in 2009 there was a 0.067% decrease in CO_2 emissions compared to the previous year, the value of the decoupling elasticity was 53.66, which indicates a state of *recessive decoupling* due to the fact that the rate of the Gross Domestic Product also decreased in percentage by 0.00125 with respect to 2008, since then, an *expansive negative decoupling* state has been registered during the following years.

Table I.2. Brazil's decoupling states by periods

Period (years)	%∆ GDP	%∆ CO_2	e	Decoupling states
1990-1994	0.1139	0.1419	1.2457	Negative expansive decoupling
1994-1998	0.1071	0.2860	2.6685	Negative expansive decoupling
1998-2002	0.0958	0.1019	1.0637	Expansive coupling
2002-2006	0.1476	0.0532	0.3605	Weak decoupling
2006-2010	0.1971	0.1799	0.9125	Expansive coupling
2010-2014	0.0920	0.2847	3.0923	Negative expansive decoupling
1990-2014	1.0277	1.5835	1.5407	Negative expansive decoupling

Source: own elaboration based on the data of GDP (billions USD, 2010) and CO_2 emissions (Mt) reported by the IEA (2017) for Brazil.

Analysis of the Kaya Identity Factors

The disaggregated analysis of the mathematical formula of the Kaya Identity allowed for the identification of the primary factors responsible for the amount of CO2 emissions. Table 3 shows that CO_2 emissions in the entire study period (1990-2014) rose significantly by 158.35%. The factor (CO_2/ TPES) that expresses the amount of CO_2 emissions per unit of the total primary energy supply from 1990 to 2014 increased 19.45%. The total supply of primary energy by total energy consumption (TPES / TFC), considered as the rate of energy inefficiency, increased by 148.13% from 1990 to 2014. The amount of final energy consumed per unit of GDP increased 27.40% from 1990 to 2014. The Brazilian population increased 37.03% from 1990 to 2014 and the (GDP/ P) ratio increased 47.98% from 1990 to 2014 and this rate depended on the activity and structure of the country's economy.

Table I.3. Disaggregated factors of the Kaya Identity for Brazil

Period(years)	%CO_2	%(CO_2/TPES)	%(TPEC/TFC)	%(CO_2/GDP)	%(GDP/P)	%P
1990-1994	14.1926	2.7924	10.6234	2.5132	4.5326	6.5629
1994-1998	28.6026	9.7296	8.4697	1.8987	4.0565	6.4020
1998-2002	10.1929	2.7570	10.4789	0.5575	3.2085	6.1752
2002-2006	5.3226	-7.4680	19.0751	-0.0051	8.9563	5.3300
2006-2010	17.9919	-1.1172	21.0944	-1.4407	14.9488	4.1478
2010-2014	28.4700	12.6421	29.8104	17.6395	5.2479	3.7611
1990-2014	158.3554	19.4566	148.1365	27.4068	47.9817	37.030

Source: own elaboration based on the data of GDP (billions USD, 2010), CO_2 emissions (Mt), TPES (Mtoe), TFC (Mtoe) and Population (millions) reported by the IEA (2017) for Brazil.

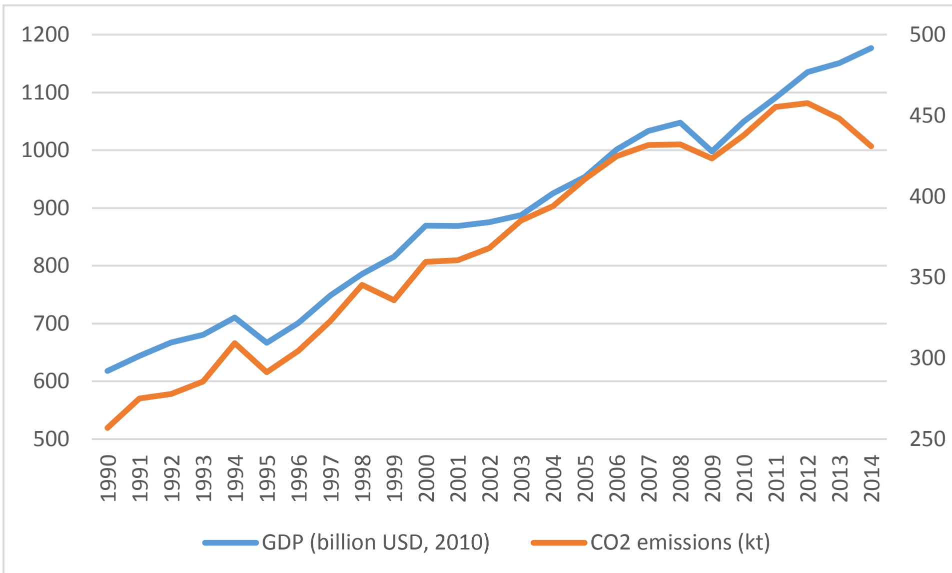
The results of the disaggregation of the Kaya Identity are consistent with the decoupling results obtained through the Tapio (2005) method, in which it is identified that during the period 2002-2006 Brazil experienced a weak decoupling state which coincides with the negative result of the percentage of (CO_2/GDP) ratio obtained with the Kaya Identity for the same period and the subsequent one. The percentage of the energy inefficiency rate (TPEC / TFC) registers an alarming increase of 148.13% and GDP per capita also increases considerably by 47.98%, being these two factors the main influences on the increase of the 158.35% elevation of CO_2 emissions.

Mexico

Decoupling Analysis

During the 2010-2014 period, it can be observed that the amount of CO_2 emissions was significantly reduced compared to the previous period, while the Gross Domestic Product of the country increased. For this reason, a *strong decoupling* state is registered with a decoupling elasticity of 0.1329. This result can be observed graphically in figure II, where the trend of GDP growth increased while at the beginning of the period 2010-2014 the trend of CO_2 emissions decreased, attributing a state of evident decoupling to the country.

Figure I.2. Trend behavior of GDP and CO2 emissions in Mexico



Source: own elaboration based on the data of GDP (billions USD, 2010) and CO_2 emissions (Mt) reported by the IEA (2017) for Mexico.

Table 4 shows the results of the elasticities resulting from the changes in CO_2 emissions and GDP for Mexico from 1990-2014, as well as the results by periods. The average decoupling status during the whole period (1990-2014) reported that Mexico experienced a *weak decoupling* state despite the fact that in the last period the registered state was a *strong decoupling* state.

Table I.4. Mexico's decoupling states by periods

Period (years)	%Δ GDP	%Δ CO2	e	Decoupling states
1990-1994	0.1497	0.2038	1.3616	Negative expansive decoupling
1994-1998	0.1064	0.1164	1.0937	Expansive coupling
1998-2002	0.1141	0.0658	0.5770	Weak decoupling
2002-2006	0.1432	0.1543	1.0774	Expansive coupling
2006-2010	0.0486	0.0309	0.6353	Weak decoupling
2010-2014	0.1207	-0.0160	-0.1329	Strong decoupling
1990-2014	0.9044	0.6775	0.74916	Weak decoupling

Source: own elaboration based on the data of GDP (billions USD, 2010) and CO_2 emissions (Mt) reported by the IEA (2017) for Mexico.

Analysis of the Kaya Identity Factors

Table 5 shows the results of the disaggregated factors of the Kaya Identity for Mexico from 1990 to 2014 and by periods. It is reported that CO_2 emissions rose by 67.75% and the percentage change in the amount of CO_2 emitted per unit of primary energy increased only by 10.37%. However, the percentage rate of energy inefficiency from 1990 to 2014 turned out to be the highest with a value of 72.31% and the period with the greatest value registered of the percentage change of (TPES/TFC) was 2010-2014.

Table I.5.Disaggregated factors of the Kaya Identity for Mexico.

Period (year)	%CO2	%CO2/TPES	%TPEC/TFC	%CO2/GDP	%GDP/P	%P
1990-1994	20.3877	9.3774	13.0014	4.7096	7.5724	6.8795
1994-1998	11.6479	4.3288	18.2993	0.1729	4.5491	5.8349
1998-2002	6.5863	-0.5030	15.8947	-4.3325	6.1023	5.0055
2002-2006	15.4375	-1.3947	14.2902	0.0011	9.0652	4.8249
2006-2010	3.0931	7.7770	-19.6363	-1.6926	-0.5009	5.3961
2010-2014	-1.6052	-8.5249	21.0929	-12.2026	6.9681	4.7698
1990-2014	67.7580	10.3750	72.3130	-11.9122	38.5179	37.4870

Source: own elaboration based on the data of GDP (billions USD, 2010), CO_2 emissions (Mt), TPES (Mtoe), TFC (Mtoe) and Population (millions) reported by the IEA (2017) for Mexico.

The disaggregated value of the percentage (CO_2/ GDP) ratio shows that from 1990 to 2014 the relationship between economic growth and CO_2 emissions in Mexico is negative. During the period 2010-2014 the value of the percentage change with respect to the previous period of CO_2 emissions per unit of GDP is -12.206%, which corroborates the result of the decoupling elasticity for Mexico during the same period.

Argentina

Decoupling Analysis

The results of the decoupling analysis for Argentina with the Tapio (2005) method are shown in Table 6, it can be observed that the general decoupling status from 1990 to 2014 is a *weak decoupling* state and not in any period did a strong decoupling occur. 1990-1994 was the period with the lowest elasticity value, followed by the period 2006-2010 where the resulting elasticity is equal to .432. However, during the period 1998-2002, Argentina experienced a *weak negative decoupling* state, which can be considered to be a consequence of the political-economic crisis suffered by the country in 2001.

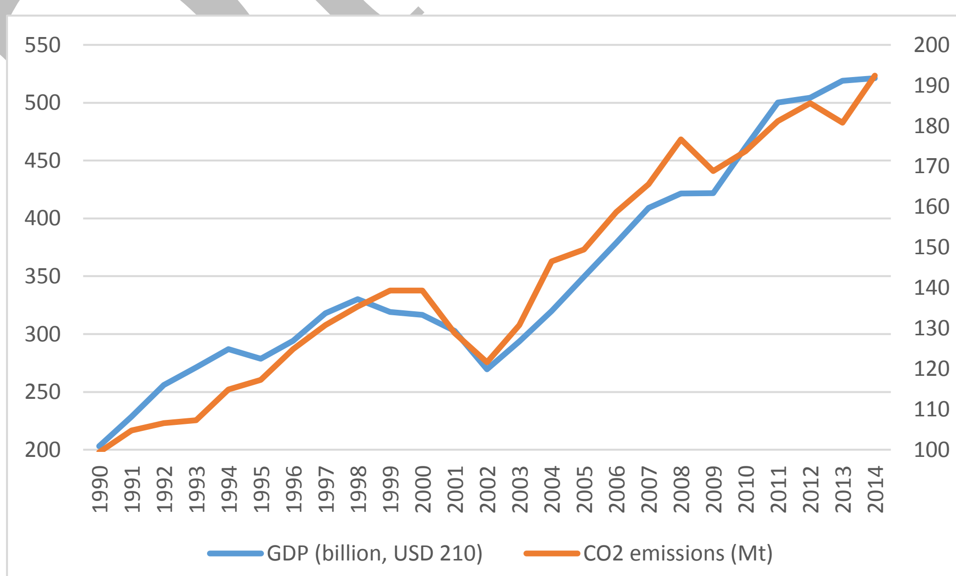
Table I. 6. Argentina's decoupling states by periods

Period (años)	**%Δ GDP**	**%Δ CO_2**	**e**	**Decoupling states**
1990-1994	0.4136	0.1561	0.3775	Weak decoupling
1994-1998	0.1510	0.1780	1.1787	Expansive coupling
1998-2002	-0.1835	-0.1015	0.5534	Weak negative decoupling
2002-2006	0.4046	0.3050	0.7538	Weak decoupling
2006-2010	0.2186	0.0945	0.4325	Weak decoupling
2010-2014	0.1291	0.1075	0.8329	Expansive coupling
1990-2014	1.5679	0.9361	0.5970	Weak decoupling

Source: own elaboration based on the data of GDP (billions USD, 2010) and CO_2 emissions (Mt) reported by the IEA (2017) for Argentina.

Figure I.3 shows the growth trend of Gross Domestic Product and CO_2 emissions from Argentina for the period 1990-2014, it is observed that the state of strong decoupling did not occur in any period, and it is even observed that since the crisis in 2001 and 2002 the CO_2 emissions increased at a faster rate than the growth of Gross Domestic Product. However, the graphic representation presented in this study is only an estimate of the growth trend of variables that are not measured under the same units.

Figure I.3. Trend behavior of GDP and CO2 emissions in Argentina.



Source: own elaboration based on the data of GDP (billions USD, 2010) and CO_2 emissions (Mt) reported by the IEA (2017) for Argentina.

Analysis of the Kaya Identity Factors

In a country that was affected by a crisis where in only one period (1998-2002) a decrease in GDP of 18.35% was reported compared to the previous period, it is expected that the factors that intervene in the amount of CO_2 emitted have relatively low percentage rates of change. Table 7 shows the results of the disaggregated factors of the Kaya Identity for Argentina from 1990 to 2014 and by periods.

From 1990 to 2014, CO2 emissions rose by 93.61%, the increase in the resulting energy inefficiency rate was 54.01% and the population growth registered an increase of 31.31% while economic growth per person turned out to be 95.55%

Table I.7. Disaggregated factors of the Identity of Kaya for Argentina.

Period (years)	**%CO_2**	**%CO_2/TPES**	**%TPEC/TFC**	**%CO_2/GDP**	**%GDP/P**	**%P**
1990-1994	15.6168	-0.0504	-14.2857	-18.2148	33.8810	5.5912
1994-1998	17.8067	4.9447	-6.43274	0.4355	9.7705	4.8611
1998-2002	-10.1580	-5.5799	5.9375	10.0403	-21.9108	4.5529
2002-2006	30.5073	2.0076	35.3244	-0.0262	34.5367	4.4074
2006-2010	9.4575	1.3041	19.6185	-10.1819	16.9580	4.1961
2010-2014	10.7586	0.5932	11.9817	-1.9114	8.2931	4.2697
1990-2014	93.6103	2.9519	54.0100	-24.6053	95.5544	31.3168

Source: own elaboration based on the data of GDP (billions USD, 2010), CO_2 emissions (Mt), TPES (Mtoe), TFC (Mtoe) and Population (millions) reported by the IEA (2017) for Argentina.

The percentage increase in the change between CO_2 emissions and the GDP from 1990 to 2014 was estimated at -24.60%, however, this value is not representative of a truly negative relationship since the variable that mainly decreased was the GDP and not CO_2 emissions. This can be corroborated with the previous results of the decoupling analysis.

Colombia

Decoupling analysis

The results obtained with the Tapio (2005) method show that during the entire study period (1990-2014) Colombia has experienced a *weak decoupling* state, with percentage increases in GDP and CO_2 emissions of 135.87% and 58.36% respectively. During the period 1998 – 2002 a *strong decoupling* state was experienced. Table 8 shows the results of the decoupling analysis.

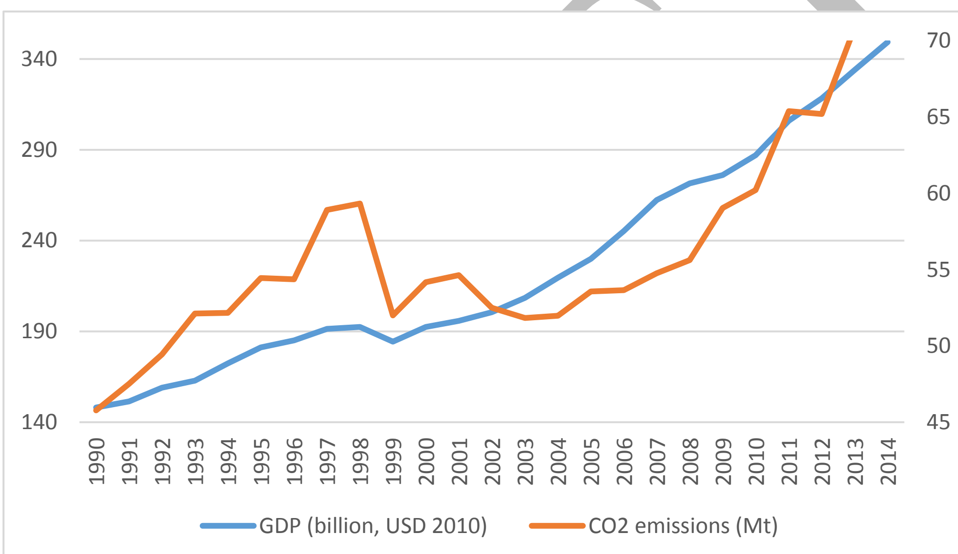
Table I.8. Colombia's decoupling states by periods

Period (years)	%Δ GDP	%Δ CO_2	e	Decoupling states
1990-1994	0.1638	0.1395	0.8518	Expansive coupling
1994-1998	0.1167	0.1374	1.1770	Expansive coupling
1998-2002	0.0425	-0.1150	-2.7043	Strong decoupling
2002-2006	0.2229	0.0217	0.0973	Weak decoupling
2006-2010	0.1698	0.1222	0.7197	Weak decoupling
2010-2014	0.2167	0.2041	0.9419	Expansive coupling
1990-2014	1.3587	0.5836	0.4295	Weak decoupling

Source: own elaboration based on the data of GDP (billions USD, 2010) and CO_2 emissions (Mt) reported by the IEA (2017) for Colombia.

Figure IV shows the decoupling trend of Colombia from 1990 to 2004, with the help of this graph the behavior of the country's GDP-CO_2 ratio is easily analyzed, in which it is observed that the state of *strong decoupling* obtained in the period 1998-2002 was due to a sudden drop in CO_2 emissions in 1999, which caused the elastic decoupling value obtained by the Tapio method to be negative for that period. However, during the final years of study, it is observed that the growth trend of the variables under study begins to be increasingly coupled.

Figure I.4. Trend behavior of GDP and CO2 emissions in Argentina.



Source: own elaboration based on the data of GDP (billions USD, 2010) and CO_2 emissions (Mt) reported by the IEA (2017) for Colombia.

Analysis of the Kaya Identity Factors

Table I.9 shows the results of the disaggregated factors of the Kaya Identity for Colombia from 1990 to 2014 and by periods. It is reported that despite the fact that CO_2 emissions rose 58.36%, the percentage change in the amount of CO_2 emitted per unit of primary energy only increased by 12.77%. The population increase resulting from 1990 to 2004 was 39.45% and the energy inefficiency rate from 1990 to 2014 was 57.33%, however, in the period from

1998 to 2002 this same rate showed negative percentage change values with respect to the previous period of -35.14%. This decrease in the energy inefficiency rate could be a reason for the result of -2.70 for the decoupling elasticity for the same period.

Table I.9. Disaggregated factors of the Kaya Identity for Colombia

Period (years)	**%CO_2**	**%(CO_2/TPES)**	**%(TPEC/TFC)**	**%(CO_2/GDP)**	**%(GDP/P)**	**%P**
1990-1994	13.9580	1.7722	-3.7593	-2.0864	8.3259	7.4409
1994-1998	13.7435	7.3694	29.4921	0.2912	4.8160	6.5453
1998-2002	-11.5099	0.8856	-35.1432	-15.1224	-1.6125	5.9648
2002-2006	2.1710	-9.5641	44.4186	-0.0820	15.9587	5.4606
2006-2010	12.2273	2.4075	41.3848	-4.0698	11.6895	4.7445
2010-2014	20.4118	10.4631	-4.6697	-1.0348	16.9100	4.0722
1990-2014	58.3660	12.7793	57.3308	-32.8615	69.1483	39.4514

Source: own elaboration based on the data of GDP (billions USD, 2010), CO_2 emissions (Mt), TPES (Mtoe), TFC (Mtoe) and Population (millions) reported by the IEA (2017) for Colombia.

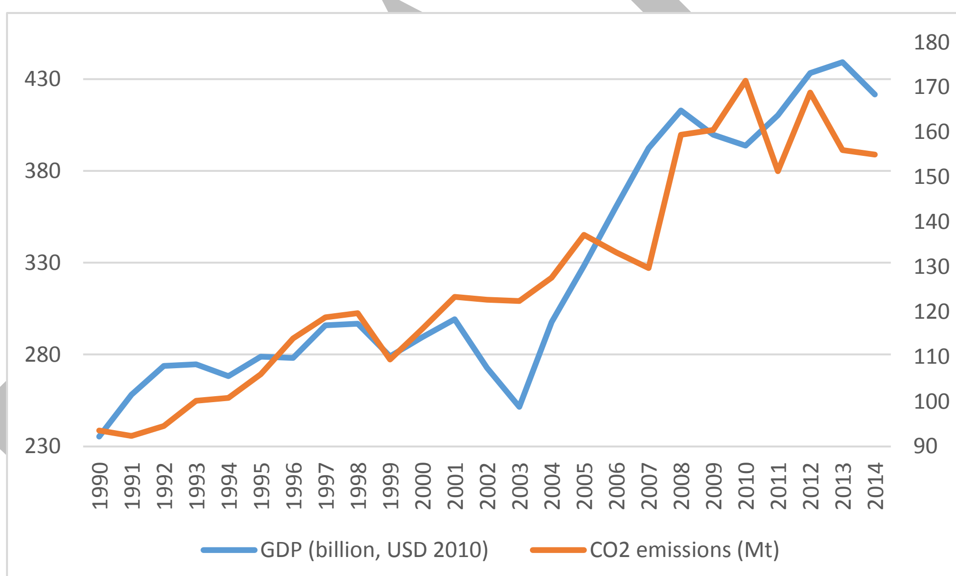
The percentage of (CO_2/GDP) ratio resulting from 1990 to 2004 shows a value of -32.86, this result would lead us to think that the relationship between the amount of CO_2 emitted per unit of GDP is negative, indicating that economic growth is not a factor in the increase in the country's CO_2 emissions. However, thanks to the tests carried out in this study, we can analyze that in the period 1998-2004, when the *strong decoupling* state was presented, the rate of the energy inefficiency was negative, but in the following periods the energy factor began to be a problem, which made it a positive factor in the increase of CO_2 emissions that could be responsible for the *expansive coupling* situation in the last period of study 2010-2014.

Venezuela

Decoupling analysis

During the period 2010-2014, Venezuela registered a general state of *expansive coupling*, the resulting elasticity was 0.8297. A *strong decoupling* state was recorded during the period 2010-2014, where the resulting elastic value was -1.36. Figure V shows Venezuela's trend path of decoupling, where it is observed that the country experienced a considerable decline in GDP during the years 2009 and 2010, probably caused by the global recession of 2008 and other various political problems. The recovery of the GDP occurred in 2012, however, the CO_2 emissions remained on the rise from 2008 to 2010. In the period 2010-2014 the CO_2 emissions registered a behavior both upwards and downwards, causing a *strong decoupling* state during this period as shown in Table 10.

Figure I.5. Trend behavior of GDP and CO2 emissions in Venezuela.



Source: own elaboration based on the data of GDP (billions USD, 2010) and CO_2 emissions (Mt) reported by the IEA (2017) for Venezuela.

Table I.10. Venezuela's decoupling states by periods

Period (years)	%∆ GDP	%∆ CO_2	e	Decoupling states
1990-1994	0.1395	0.0771	0.5528	Weak decoupling
1994-1998	0.1067	0.1874	1.7552	Expansive negative decoupling
1998-2002	-0.0812	0.0252	-0.3107	Strong negative decoupling
2002-2006	0.3225	0.0859	0.2665	Weak decoupling
2006-2010	0.0917	0.2869	3.1267	Expansive negative decoupling
2010-2014	0.0705	-0.0961	-1.3624	Strong decoupling
1990-2014	0.7912	0.6565	0.8297	Expansive coupling

Source: own elaboration based on the data of GDP (billions USD, 2010) and CO_2 emissions (Mt) reported by the IEA (2017) for Venezuela.

Analysis of the Kaya Identity Factors

The results of the disaggregated analysis of the Kaya Identity for Venezuela are shown in Table 11. From 1990 to 2014 the CO_2 emissions rose by 65.65% and the main factors that influenced this increase, according to this analysis, were the energy inefficiency which increased 71.16%, and the population which registered an increase of 54.53%.

Table I.11. Disaggregated factors of the Kaya Identity for Venezuela

Period (years)	%CO_2	%(CO_2/TPES)	%(TPEC/TFC)	%(CO_2/GDP)	%(GDP/P)	%P
1990-1994	7.7169	-14.5901	49.5620	-5.4765	4.1511	9.4159
1994-1998	18.7437	13.2978	-6.4909	1.3566	2.0384	8.4675
1998-2002	2.5236	-6.8404	14.7181	11.5869	-14.7417	7.7641
2002-2006	8.5989	-0.1722	17.3794	-0.0655	23.4124	7.1653
2006-2010	28.6925	11.3925	-9.5736	17.8756	2.4754	6.5393
2010-2014	-9.6110	-3.0762	0.5143	-15.5671	1.1592	5.8275
1990-2014	65.6584	-2.8382	71.1678	-7.5200	15.9172	54.5317

Source: own elaboration based on the data of GDP (billions USD, 2010), CO_2 emissions (Mt), TPES (Mtoe), TFC (Mtoe) and Population (millions) reported by the IEA (2017) for Venezuela.

The percentage ratio of CO_2 emissions per unit of GDP shows corroboration with the results obtained from the graphic observation and the decoupling analysis by the Tapio (2005) method.

I.6 CONCLUSIONS

This study analyzed the decoupling status of economic growth from the amount of CO_2 emissions through tendential observation and the analysis of the decoupling elasticity following a method proposed by Tapio (2005). Additionally, in this research the primary factors of CO_2 emissions were identified using the disaggregated form of the Kaya Identity. These tests were applied to 5 of the largest economies in Latin America (Brazil, Mexico, Argentina, Colombia and Venezuela) from 1990 to 2014.

The analysis of the decoupling degree makes it possible to determine whether their environmental mitigation strategies are sufficient or not. The results of the decoupling analysis carried out in this research can facilitate the process of formulating public policies or environmental strategies with the aim of reducing the CO_2 emissions of the countries studied.

According to the results obtained with the analysis of the decoupling elasticity and the observation of the decoupling trend path, only Mexico and Venezuela experienced *strong decoupling states*, which can mean that these countries are well directed towards the realization of the goals proposed in the Paris Agreement. Brazil, Argentina and Colombia did not present strong decoupling states in any of the study periods, and instead the three countries reported states of *expansive coupling*, indicating in this way the urgent need to take environmental measures to achieve the reduction of CO_2 emissions.

According to the results of the disaggregation of the mathematical formula of the Kaya Identity, the main primary factors that influence the amount of CO_2 emitted in three of the five countries under study is the energy inefficiency index. From 1990 to 2014, the percentage change in the total energy supply per unit of total energy consumed (TPES/ TFC) in Brazil was 148.13%, in Mexico it was 72.31%, and in Venezuela it was 71.16%. For

Argentina and Colombia, the main factor turned out to be the (GDP/ P) with a percentage change of 95.55% and 69.14% respectively.

In order for the countries under study to reduce their emissions, it is necessary to increase the generation and use of clean energies to reduce the high rates of energy inefficiency that were reported, as well as applying strategies to transform the traditional economic system into a low-carbon system.

Similarly, the disaggregated analysis of Kaya's Identity is a useful tool for the application of policies in the various sectors considered by this mathematical formula, with the aim of reducing the amount of CO_2 emissions and being able to achieve the goals and objectives of international agreements.

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CHAPTER II

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Non-parametric Data Envelopment Analysis approach for measuring states of inefficiency and decoupling in the European Union

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CHAPTER II. Non-parametric Data Envelopment Analysis approach for measuring states of inefficiency and decoupling in the European Union.

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II.1 Abstract

The objective of this research is to propose the application of non-parametric models of enveloping data to evaluate the decoupling of the gross domestic product from greenhouse gas emissions and to analyse the effects of two of the main factors of environmental degradation, using variables such as population growth and gross domestic product as the main factors affecting the increase of greenhouse gas emissions and energy inefficiency. The models proposed in this research were applied to analyse the situation of inefficiency and decoupling of the 28 member countries of the European Union using data from the years 1995, 2000, 2005, 2010 and 2014. It was found that Luxembourg, Austria, Denmark, Malta, United Kingdom and Italy are the economies that turn out to be the most decoupled, and according to the analysis, the restructuration of public polices is urgent to decrease the inefficiency indexes.

Keywords: European Union, Economic growth, greenhouse gas emissions, decoupling, inefficiency, population growth, energy inefficiency.

JEL Classification: Q56

II.2 INTRODUCTION

The global crisis we face today is a combination of several worrisome changes, among which we can include the crisis for food security (CGIAR, 2009), high levels of environmental degradation, loss of biodiversity (Warning and Assessment, 2011) and climate change (Richardson et al., 2009). In order to address some of these issues, the European Union (EU) and its member states launched a sustainable growth strategy in 2010, the so-called "Europe 2020 Strategy" (Saucedo-Acosta, 2013), in which five objectives have been set in terms of employment, innovation, education, social integration, climate change and energy. The latter being one of the most challenging objectives and in which the integrated participation of the EU members is important, that is why these economies have committed themselves to reducing greenhouse gas emissions (GHG) by 20%, increasing the use of renewable energies by 20% and increasing energy efficiency by 20% (Commission, 2010).

To achieve the goals set, the EU has proposed a series of long-term political plans in the fields of energy, transport, industry, communication and technologies to combat climate change, converting the economies of the EU member states into low carbon economies. However, the EU is in the process of achieving the goals mentioned above, with the energy sector being one of the biggest challenges in which no significant progress has been made, which is why it is necessary to make greater efforts and focus on structuring policies and actions that improve energy yields (European Commission, 2010).

The assessment of the main driving forces in the increase of the GHG emissions and a decoupling evaluation can act as a tool to help the decision maker to formulate and evaluate public policies on environmental matters. The term decoupling describes the relationship between economic growth and environmental damage, and in this paper we use this term to characterise the relationship between the increase in gross domestic product (GDP) and GHG emissions.

This research proposes the application of non-parametric models of enveloping data to analyse population growth and economic growth (measured in GDP) as two of the main pollution factors in the 28 member countries of the EU, using data from 1995, 2000, 2005, 2010 and 2014. This approach can also be used to analyse the decoupling situation between GDP and GHG emissions.

The decoupling GDP-GHG has been studied under various parametric methodologies which have used processes of decomposition of identities or formulas, elastic change measures and the evaluation of the existing correlation using diverse panel data methodologies. However, the Data Envelopment Analysis (DEA) can be used as a non-parametric alternative to calculate the decoupling of economic growth and GHG emissions. This kind of approach is based on the productivity theory to measure the efficiency of a cluster of observations.

The DEA models proposed in this paper attempt to measure inefficiency indexes using data series of Population and GDP as inputs and GHG emissions and energy efficiency as outputs of environmental damage.

This work is composed of 6 sections, the second section shows the literature related to decoupling and the various parametric methods used to measure it, the third section examines the non-parametric overview of the DEA that has been used to measure decoupling, the fourth section shows the DEA methods proposed and the same ones will be applied in the fifth section to the data series of the EU member countries, the last section covers the conclusions of the investigation.

According to the results obtained, there is a long way to go to meet the environmental goals set, but in the last study period Luxembourg, Austria, Denmark, Malta, United Kingdom and Italy are the countries that could be considered the most decoupled of the European Union. Regarding the analysis of the population as one of the main inputs of environmental degradation, the highest inefficiency indices in 2014 were obtained by Malta, Croatia, Latvia, Romania and Hungary.

II.3. LITERATURE REVIEW

The term decoupling has been used in environmental studies to characterise the relationship between economic activity and the degradation of the environment. This has not been the first concept proposed to describe the effort that economies have made to achieve economic growth causing the least damage to the environment.

However, controversy arises regarding the real possibility of achieving the decoupling of economic growth with respect to the level of ecological degradation, but several studies have reported the possibility of total or partial decoupling of the economy from CO_2 emissions and other studies from greenhouse gases. To characterise this relationship, different tools have been used, one of which is the IPAT approach, in which different environmental impacts can be analysed at different levels, since according to Ehrlich and Holdren (1970) and Commoner (1971) the main driving forces of the GHG increase are: the population, affluence and technology development.

In 1989, another approach emerged called the Kaya Identity (equation 1), which offers an explanatory analysis of different factors that influence the amount of emissions and their variation over periods of time (Yamaji et al., 1991).

$$CO_2 = P \cdot \frac{GDP}{P} \cdot \frac{Energy}{GHG} \cdot \frac{CO_2}{Energy} \qquad (1)$$

The Kaya Identity has also been used in several studies where the carbonisation index and energy intensity have been considered as a factorial index (Ang and Zhang, 1999, Mielnik and Goldemberg, 1999, Sun, 2005). Additionally, Zhang (2000) used the decomposed form of the Kaya Identity, as shown in formula (2), where CO_2 is equal to CO_2 emissions, (CO_2 / TPES) expresses the amount of CO_2 emissions per unit of the total primary energy supply (TPES) which depends on the emission factors and the fuel combination, (TPES / TFC) is the total supply of primary energy by total energy consumption (TFC) which depends on the efficient conversion of energy and the combination of fuels, (TFC / GDP) is the amount of final energy consumed per unit of GDP, which depends on the final use of energy intensity, (GDP / P) is GDP divided by population (P) and depends on the activity and the structure of the economy.

$$KI_d = CO_2 \cdot \frac{CO_2}{TPES} \cdot \frac{TPES}{TFC} \cdot \frac{CO_2}{GDP} \cdot \frac{GDP}{P} \cdot P \quad (2)$$

The Kaya Identity decomposition form was also used to analyse Ireland's primary emission factors from 1990 to 2010 (O'Mahony, 2013). Ren et al. (2014), analysed the impacts of CO_2 emissions from China's manufacturing industry during the 1996-2010 period through the logarithmic average currency index (LMDI) based on the modification of the Kaya Identity. Robalino-López et al. (2015), analysed the possible changes of the main primary CO_2 emission factors in Venezuela for the period 1980-2025, using an extended methodology of the Kaya Identity and hypothetical Kuznets Curves. The decoupling status of CO_2 emissions and GDP were studied alongside the main factors of the increase of CO_2 emissions in South Africa from 1990 to 2012 and were evaluated using the decomposition of the Kaya Identity (Lin et al., 2015).

Another of the methodologies used to measure the decoupling of economic growth and environmental damage is the so-called decoupling elasticity. Vehmas et al. (2003), built a frame of reference for the different linking states, which can occur in sectors, countries or groups of countries. Tapio (2005), studied the relationship between GDP, traffic volume and CO_2 emissions from transport in 15 EU countries, he also analysed the special case of road traffic in Finland between 1970-2001 and proposed a new framework for reference which proposes 8 visible decoupling states. Enevoldsen et al. (2007), followed a decoupling elasticity methodology to study the impact of energy prices and taxes on energy efficiency and carbon emissions of 10 industrial sectors in three Scandinavian countries. Lu et al. (2015) investigated the state of decoupling by elasticity and the influential factors in energy consumption and CO_2 emissions of the industrial sector of the Jiangsu province in China from 2005 to 2012.

However, these tools (IPAT, KAYA, decoupling elasticity) are approaches that have limitations because they are multiplicative identities, so certain proportions are assumed between the different variables (Lozano and Gutierrez, 2008).

In this way, various panel data analysis methodologies were proposed as tools that can measure decoupling. Niu et al. (2011), evaluated the relationship between energy consumption, GDP and CO_2 emissions for 8 countries in Asia and the Pacific using a panel regression model to estimate the parameters of the variables. Hatzigeorgiou et al. (2011), studied the causal relationship between GDP, energy intensity and CO_2 emissions of Greece from 1977 to 2007, using Johansen co-integration tests and Granger causality tests, based on a multivariate correction vector model. Farhani et al. (2013), investigated the causal relationship between energy consumption, CO_2 emissions, economic growth, trade opening and urbanisation of 11 countries in the Middle East and North Africa from 1980 to 2009 using co-integration and causality tests and concluded that with higher energy consumption there is greater economic growth and greater economic opening, therefore there is an increase in the amount of CO_2 emissions. Kasman and Duman (2015), investigated the causal relationship between energy consumption, CO_2 emissions, economic growth, commercial openness and urbanisation of members and candidates to the EU, using unit root tests, co-integration panel and causality tests.

The analysis through panel data has also been used to evaluate the hypothesis known as the Environmental Kuznets Curve (EKC) hypothesis, where according to Grossman and Krueger (1991), there is an empirical relationship between per capita income and certain environmental measures, and the environmental quality tends to improve as economic development reaches a certain high level, producing a relationship where environmental quality could be represented graphically in the form of an inverted "U".

Some of the investigations that used panel data to evaluate the EKC are: Nasir and Rehman (2011), who investigated the relationship between CO2 emissions, income, energy consumption and commercial openness in Pakistan from 1997 to 2008, finding that there is no evidence in that country of the presence of the EKC in the short term. Hamit-Haggar

(2012), estimated the long-term relationship and the causal relationship between greenhouse gas emissions, energy consumption and economic growth for Canadian industrial sectors from 1990 to 2007 using a panel data methodology based on the hypothesis of the EKC finding that there is a long-term equilibrium between energy consumption as a significantly positive impact on greenhouse gas emissions while there is a non-linear relationship between emissions and economic growth consistent with that established in the hypothesis of the EKC. Lapinskienė et al. (2014), used various panel data tests to confirm the presence of the EKC in 27 countries of the European Union from 1995 to 2010, using the cubic equation to validate the hypothesis.

However, these methodologies have the disadvantage of being based on regressions, therefore their measurements tend to the mean and that value does not always describe the totality of the individuals in a study.

II.3.1. PREVIOUS STUDIES ON DATA ENVELOPMENT ANALISYS (DEA) TO MEASURE DECOUPLING LEVEL

The DEA models emerge as a non-parametric alternative that serves to calculate the decoupling of economic growth and GHG emissions. This approach was formally introduced by Charnes, Cooper and Rhodes in 1978, but was based on Farell's productivity efficiency theory (1957), which proposed to visualise efficiency from a non-ideal real perspective, where production will be evaluated under the relative behaviour of different units in which the presence of multiple inputs and outputs makes it difficult to compare their performance (Lopez et al., 2007). Therefore, the efficiency measures will be relative and not absolute, and the value reached by a certain productive unit will correspond to an expression of the observed deviation with respect to those considered more efficient, given the information available (Schuschny, 2007)

The DEA method consists of a mathematical programming technique that, given a set of decision making units (DMU), could work with different contexts of inputs and products to be able to identify another set of units that serve to build a base production boundary with which we can compare the original DMU.

To analyse how different DMUs evolve in terms of efficiency during different periods of time, the Malmquist indexes (1953) are used, which represent different relationships in multi-product and multi-input spaces based on distance calculation, existing between one period and the other.

Schuschny (2007), applied DEA models and Malmquist indexes to study the efficiency of energy consumption and the substitution of non-renewable energies for renewable energy sources in Latin America and the Caribbean. Zhou et al. (2008), used DEA models to measure the environmental performance of 8 regions of the world to demonstrate the advantages between the use of DEA models with variable and non-increasing returns on DEA models with constant returns. Zhou and Ang (2008), proposed a decomposition methodology based on enveloping data to solve 7 variables that act as factors that affect the change of emissions over time by the use of technologies. Lozano and Gutierrez (2008), studied the environmental performance of most countries of Annex B of the Kyoto Protocol, using DEA models under different specifications of inputs and products to characterise the relationship between the different factors that, according to the Identity of Kaya, increase the amount of CO_2 emissions from the countries under study. Zhou et al. (2010), solved Malmquist indexes to measure the performance in the total change of CO_2 emissions, considering the technological innovations of 18 of the countries with the highest amount of emissions from 1997 to 2004.

II.4. METHODS AND DATA

To fulfill the purposes of this research, a non-parametric DEA methodology was used to analyse the decoupling level and to evaluate the amount of population as a factor of environmental degradation of the 28 EU member countries: Germany, Austria, Belgium, Bulgaria, Cyprus, Croatia, Denmark, Slovakia, Slovenia, Spain, Estonia, Finland, France, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, the United Kingdom, Czech Republic, Romania and Sweden, for the years 1995, 2000, 2005, 2010 and 2014.

The objectives of this research were measured through efficiency data from the application of DEA models using data from: GDP from the World Bank database (2017) referred in dollars at constant prices to 2010, population growth (P) from the Eurostat database (2017), primary energy production (PE) in thousands of tonnes of oil equivalent (TOE) from the Eurostat database (2017) and greenhouse gas (GHG) emission data in millions of tonnes (Mt) from the Eurostat database (2017) which includes CO_2 emissions, N_2O in CO_2 equivalent, CH_4 in CO_2 equivalent, HFC in CO_2 equivalent, PFC in CO_2 equivalent, SF_6 in CO_2 equivalent and NF_3 in CO_2 equivalent.

The methodological process consisted in modelling the existing relationships between, GDP, P, PE and GHG through the formulation of two models to analyse two of the main pollution factors that according to Kaya (1990) and Yamani et al. (1991) are: gross domestic product and population growth.

II.4.1 PROPOSED DEA MODELS

The first proposed model (3) considers GDP as input and GHG and PE as controlled outputs. This model analyses the efficiency of the decoupling relationship between greenhouse gases and economic growth (GHG-GDP) of the countries under study associated with energy efficiency values (translated in terms of primary energy production). This proposed approach can be can be written vectorially as g = ($GHGI_0$ PE_0| PIB_0).

$$MAX\ \beta$$

$$s.t \qquad (3)$$

$$\sum_{J-1}^{N} \lambda_J\, GDP_J \leq GDP_0$$

$$\sum_{J-1}^{N} \lambda_J\, PE_J = PE_0 \cdot (1+\beta)$$

$$\sum_{J-1}^{N} \lambda_J \, GHG_J = GHG_0 \cdot (1 + \beta)$$

$$\lambda_j \geq 0 \ \forall j \qquad \beta \geq 0$$

In (3), N represents the number of observations in the sample, β is the size of the inefficiency and λj are non-negative multipliers that will define the linear combination of the sample observations. The values of β greater than zero will denote a certain degree of efficiency in the parameters, the larger the value of β * the greater the inefficiency.

The second model (4) is formulated in a way that inefficiency can be found, given the variables P, PE and GHG. Where Population is considered as an input and PE and GHG are the controlled outputs. The model described vectorially remains as: $g = (GHG_0 \ PE_0 \mid P_0)$.

$$MAX \ \beta$$

$$s.t \qquad (4)$$

$$\sum_{J-1}^{N} \lambda_J \, P_J \leq P_0$$

$$\textstyle\sum_{J-1}^{N} \lambda_J \, PE_J = PE_0 \cdot (1 + \beta)$$

$$\sum_{J-1}^{N} \lambda_J \, GHG_J = GHG_0 \cdot (1 + \beta)$$

$$\lambda_j \geq 0 \ \forall j \qquad \beta \geq 0$$

II.5 APPLICATION OF THE PROPOSED DEA APPROACH

To illustrate the DEA approach proposed in the previous section, growth data of P, GDP, PE and GHG emissions have been used, coming from the 28 member countries of the EU. Table

1 shows the β * of the computation of the model (3), with vector g = ($GHGI_0$ PE_0| PIB_0), using the Frontier Analyst software. Where the β * shows the percentages of the inefficiency values, the higher the β the greater the inefficiency.

Table II.1. Percentages of inefficiency obtained with the calculation of the DEA model (3)

Country/Period	1995	2000	2005	2010	2014
Austria	11.9	13.5	17.6	18.5	17.3
Belgium	18.7	20.4	22.4	23.6	20.9
Bulgaria	100	100	100	100	100
Croatia	32.2	30.3	34.9	40.0	35.5
Cyprus	19.5	23.8	28.0	30.2	32.2
Czech Republic	61.4	67.7	74.1	65.0	58.8
Denmark	16.1	30.8	39.6	28.1	18.5
Estonia	90.1	75.0	79.8	100	100
Finland	22.0	23.5	28.6	29.3	28.9
France	15.8	18.3	21.8	20.0	19.6
Germany	17.1	18.8	21.6	23.6	22.9
Greece	22.8	28.5	31.3	33.8	38.2
Hungary	41.4	38.7	40.0	42.8	38.1
Ireland	24.8	23.6	22.7	24.0	22.4
Italy	12.4	15.2	18.8	20.5	18.9
Latvia	41.0	34.5	31.7	43.3	38.5
Lithuania	54.1	44.4	45.1	46.2	40.1
Luxembourg	15.0	12.9	19.5	19.5	15.7
Malta	15.7	15.8	17.7	29.4	18.7
Netherlands	28.7	26.2	32.7	33.0	27.1
Poland	100	80.2	84.2	72.1	65.6
Portugal	17.1	21.2	26.7	25.2	26.4
Romania	81.3	86.2	79.4	68.9	61.6
Slovak Republic	50.4	49.9	50.4	44.1	38.0
Slovenia	28.5	29.1	32.5	35.7	33.0
Spain	15.0	18.9	22.6	21.6	22.1
Sweden	24.1	25.2	31.1	26.4	26.0
United Kingdom	36.6	43.0	35.1	24.9	18.8

Source: own elaboration based on the data:

- Gross Domestic Product (GDP) in dollars at constant prices to 2010 from the World Bank database (2017).
- Primary energy production (PE) in thousands of tonnes of oil equivalent (TOE) from the Eurostat database (2017).

- Greenhouse gas (GHG) emissions in millions of tonnes (Mt), from the Eurostat database (2017), which includes CO_2 emissions, N_2O in CO_2 equivalent, CH_4 in CO_2 equivalent, HFC in CO_2 equivalent, PFC in CO_2 equivalent, SF_6 in CO_2 equivalent, NF_3 in CO_2 equivalent

According to the results in 2014 the countries with the lowest inefficiency rate are: Luxembourg (15.7%), Austria (17.3%), Denmark (18.5%), Malta (18.7%), United Kingdom (18.8%) and Italy (18.9%). The least efficient countries regarding GDP as input and GHG, PE as controlled outputs are: Bulgaria (100%), Estonia (100%), Poland (65.5%), Romania (61.6%) and Czech Republic (58.8%), nevertheless, it should be noted that the last three countries show a rate of decrease in their index over time.

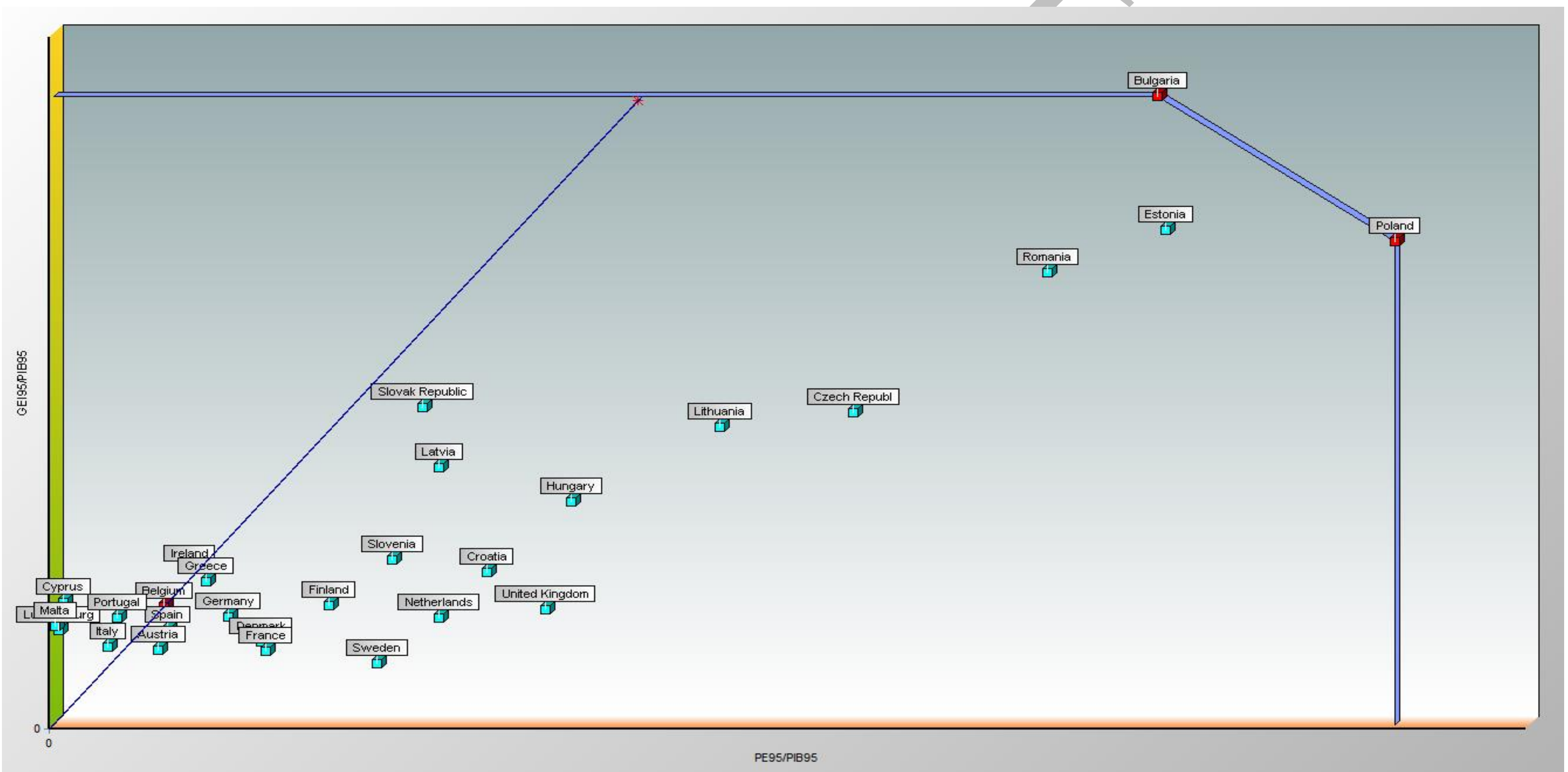
Figure 1 and Figure 2 show the evaluation of inefficiency of the EU for 1995 and 2014 respectively. In these figures, the blue line marks the inefficiency frontier and the countries that are closest to it are the countries with the highest rates of inefficiency and the countries furthest from the border are the most efficient.

According to the chart for 1995, Malta, Italy, Austria and Luxembourg seem to be the countries with the most efficiency. Bulgaria, Poland, Estonia, Romania and Czech Republic appear to be the closest to the border, which is consistent with the data in Table 1.

For 2014, the Figure 2 suggests that Luxembourg, Malta, Austria and Italy are the most efficient EU countries. Bulgaria and Estonia remain on the border, while Romania, Czech Republic and Poland are placed closest to the border.

The level of decoupling of the relationship between economic growth and the amount of greenhouse gases is reflected in Figures 1 and 2. The countries located in the furthest part of the border and nearest the Y axis are considered to be the countries with the highest level of decoupling.

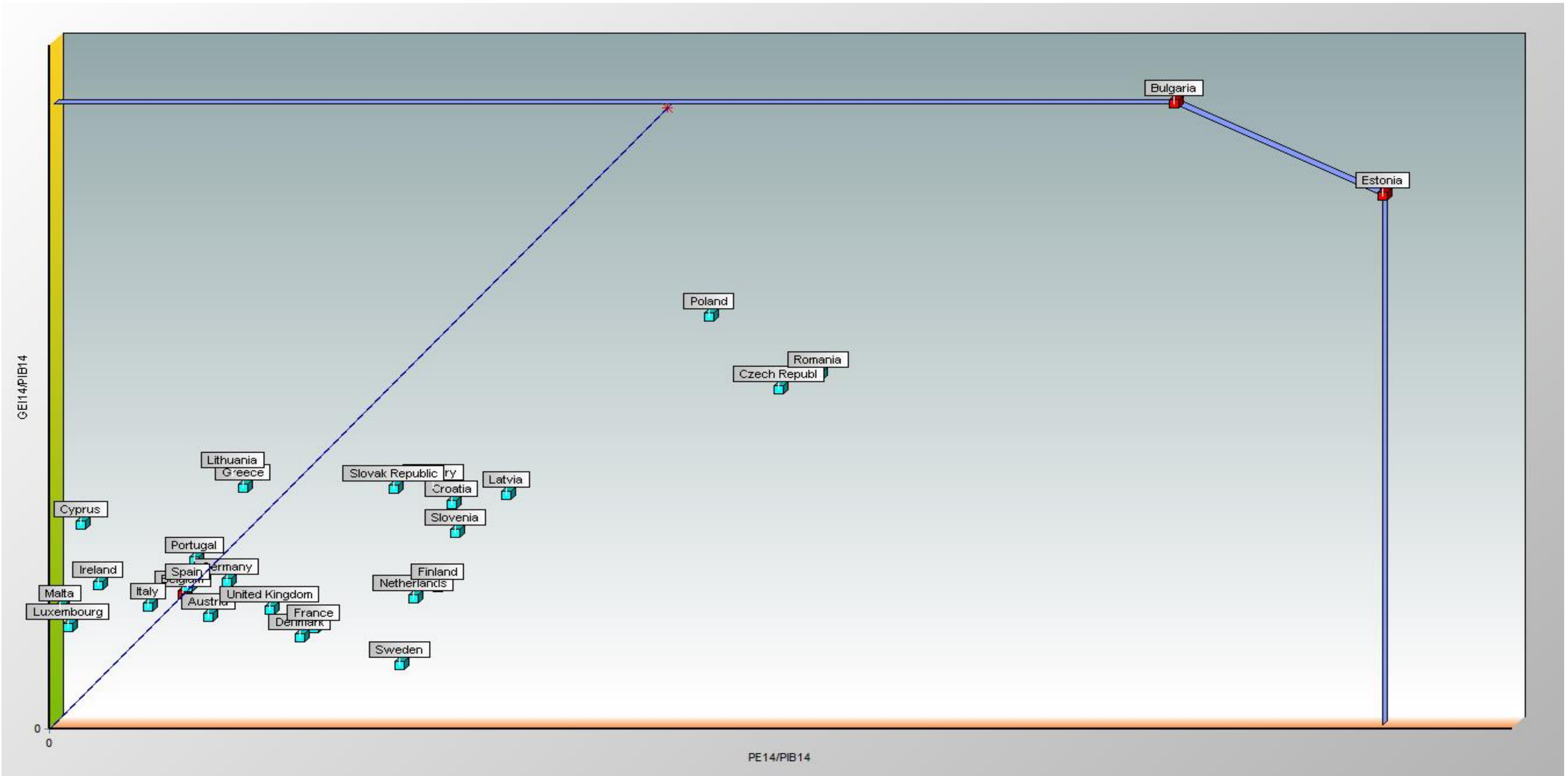
Figure II.1. Evaluation of inefficiency of the European Union in 1995, g = (GHG_0 PE_0 | GDP_0).



Source: own elaboration based on the data:

- Gross Domestic Product (GDP) in dollars at constant prices to 2010 from the World Bank database (2017).
- Primary energy production (PE) in thousands of tonnes of oil equivalent (TOE) from the Eurostat database (2017).
- Greenhouse gas (GHG) emissions in millions of tonnes (Mt), from the Eurostat database (2017), which includes CO_2 emissions, N_2O in CO_2 equivalent, CH_4 in CO_2 equivalent, HFC in CO_2 equivalent, PFC in CO_2 equivalent, SF_6 in CO_2 equivalent, NF_3 in CO_2 equivalent

Figure II.2. Evaluation of inefficiency of the European Union in 2014, g = (GHG_0 PE_0 | GDP_0).



Source: own elaboration based on the data:

- Gross Domestic Product (GDP) in dollars at constant prices to 2010 from the World Bank database (2017).
- Primary energy production (PE) in thousands of tonnes of oil equivalent (TOE) from the Eurostat database (2017).
- Greenhouse gas (GHG) emissions in millions of tonnes (Mt), from the Eurostat database (2017), which includes CO_2 emissions, N_2O in CO_2 equivalent, CH_4 in CO_2 equivalent, HFC in CO_2 equivalent, PFC in CO_2 equivalent, SF_6 in CO_2 equivalent, NF_3 in CO_2 equivalent

Table 2 shows the results of the computation of the DEA model (4) proposed in the previous section, where the inefficiency data are shown considering the variables of population, primary energy and greenhouse gases. The results suggest that the growth of the indexes of inefficiency through the years of study tend to decrease in the majority of the EU members.

Table II.2. Percentages of inefficiency obtained with the calculation of the DEA model (4)

Country/Period	1995	2000	2005	2010	2014
Austria	50.2	56.5	51.1	57.1	52.9
Belgium	71.8	78.9	61.2	66.0	58.6
Bulgaria	46.2	42.5	42.3	48.6	47.7
Croatia	29.1	33.5	34.7	39.2	31.4
Cyprus	44.1	55.9	43.6	45.8	52.2
Czech Republic	90.3	91.3	83.5	89.0	73.1
Denmark	87.3	100	100	98.2	63.4
Estonia	75.1	74.4	75.3	100	100
Finland	79.6	84.9	77.9	93.6	75.4
France	56.5	58.7	52.5	55.7	46.7
Germany	71.5	72.3	58.7	64.8	65.3
Greece	50.2	62.9	52.8	53.1	53.4
Hungary	41.6	42.3	36.3	39.0	34.6
Ireland	76.5	91.0	62.8	60.4	70.5
Italy	42.6	50.2	40.1	41.5	39.6
Latvia	24.8	24.4	25.6	34.0	33.7
Lithuania	32.8	31.2	34.9	31.3	37.1
Luxembourg	100	100	100	100	100
Malta	21.7	24.9	17.7	30.6	26.0
Netherlands	100	91.8	84.6	100	78.7
Poland	69.9	63.6	57.0	63.2	59.9
Portugal	31.7	41.3	32.8	33.4	35.5
Romania	45.8	39.3	37.8	39.5	34.4
Slovak Republic	49.2	51.8	45.1	47.5	43.9
Slovenia	50.1	56.7	52.6	58.7	47.6
Spain	40.3	51.0	42.0	40.0	41.0
Sweden	81.0	65.5	66.7	82.8	80.1
United Kingdom	100	90.0	74.2	66.4	49.2

Source: own elaboration based on the data:

- Population growth (P) from the Eurostat database (2017).
- Primary energy production (PE) in thousands of tonnes of oil equivalent (TOE) from the Eurostat database (2017).

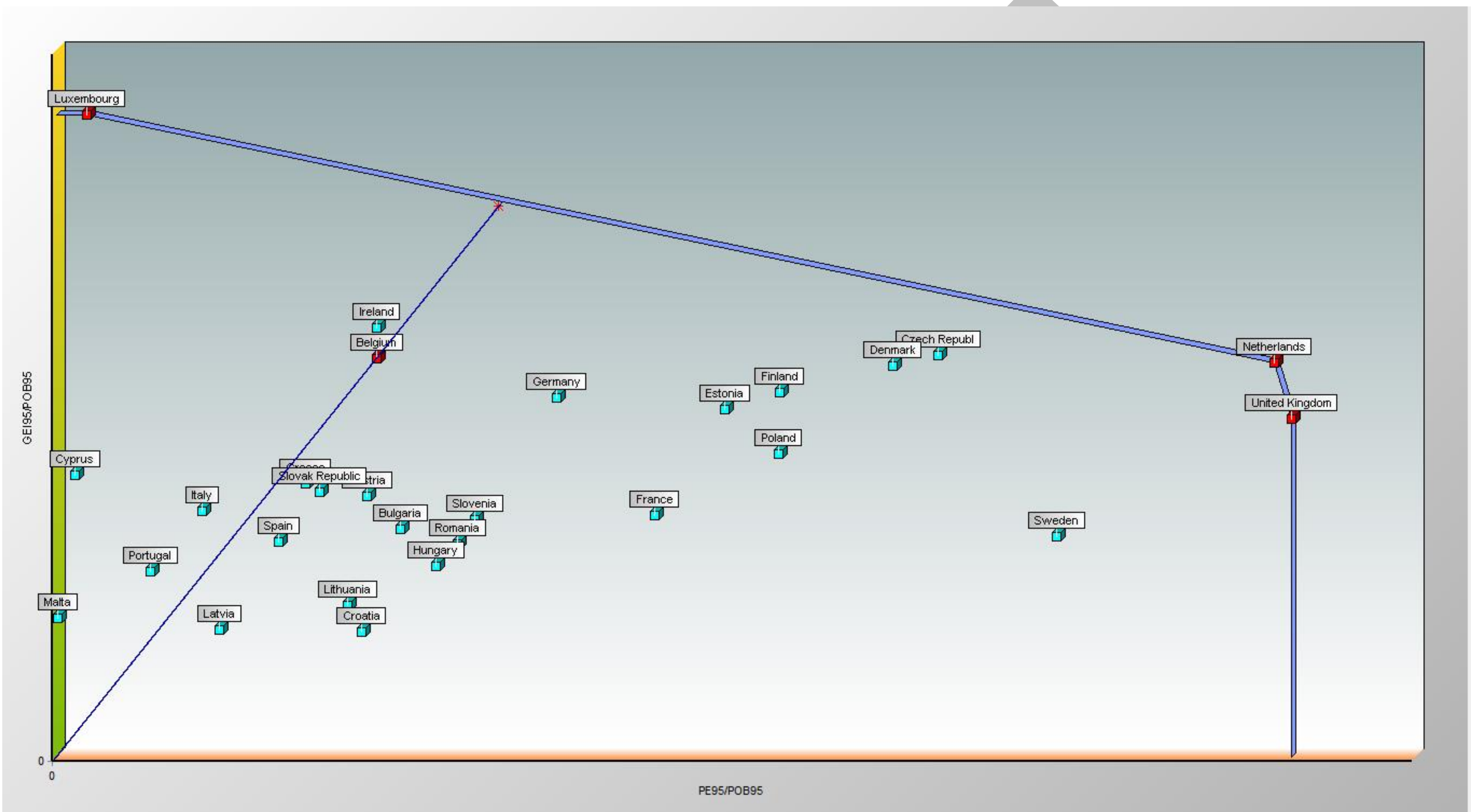
- Greenhouse gas (GHG) emissions in millions of tonnes (Mt), from the Eurostat database (2017), which includes CO_2 emissions, N_2O in CO_2 equivalent, CH_4 in CO_2 equivalent, HFC in CO_2 equivalent, PFC in CO_2 equivalent, SF_6 in CO_2 equivalent, NF_3 in CO_2 equivalent

According to the results in 2014 the amount of GHG and PE generated for the amount of population is the least efficient in Estonia (100%), Luxembourg (100%), Sweden (80.1%), Netherlands (78.7%), Finland (75.4%) and Czech Republic (73.1%). However, the vast majority of the member countries of the European Union exceed the 40% of the inefficiency index, demonstrating the existence of a severe ineffectiveness of public policies and actions aimed at improving energy efficiency and the reduction of greenhouse gas emissions. The countries with the lowest inefficiency rate are: Malta (26%), Croatia (31.4%), Latvia (33.7%), Romania (34.4) and Hungary (34.6%)

Figures 3 and 4 show the inefficiency assessment of the EU for 1995 and 2014 respectively. Where, the blue line marks the inefficiency boundary between P as input and GHG and PE as outputs. According to the graph it seems that in 1995 Malta, Latvia, Croatia, Lithuania and Portugal were the countries furthest from the border and the ones on the border or closest to it are Luxembourg, Netherlands, United Kingdom, Sweden, Czech Republic and Denmark.

Regarding the situation reported in 2014, according to the chart Malta, Croatia, Latvia, Romania and Hungary seem to be the countries furthest from the border, meaning that those are the most efficient countries when it comes to population and the corresponding GHG emissions and energy production. The countries nearest to the inefficient border or on it are Luxembourg, Estonia, Netherlands, Sweden and Finland.

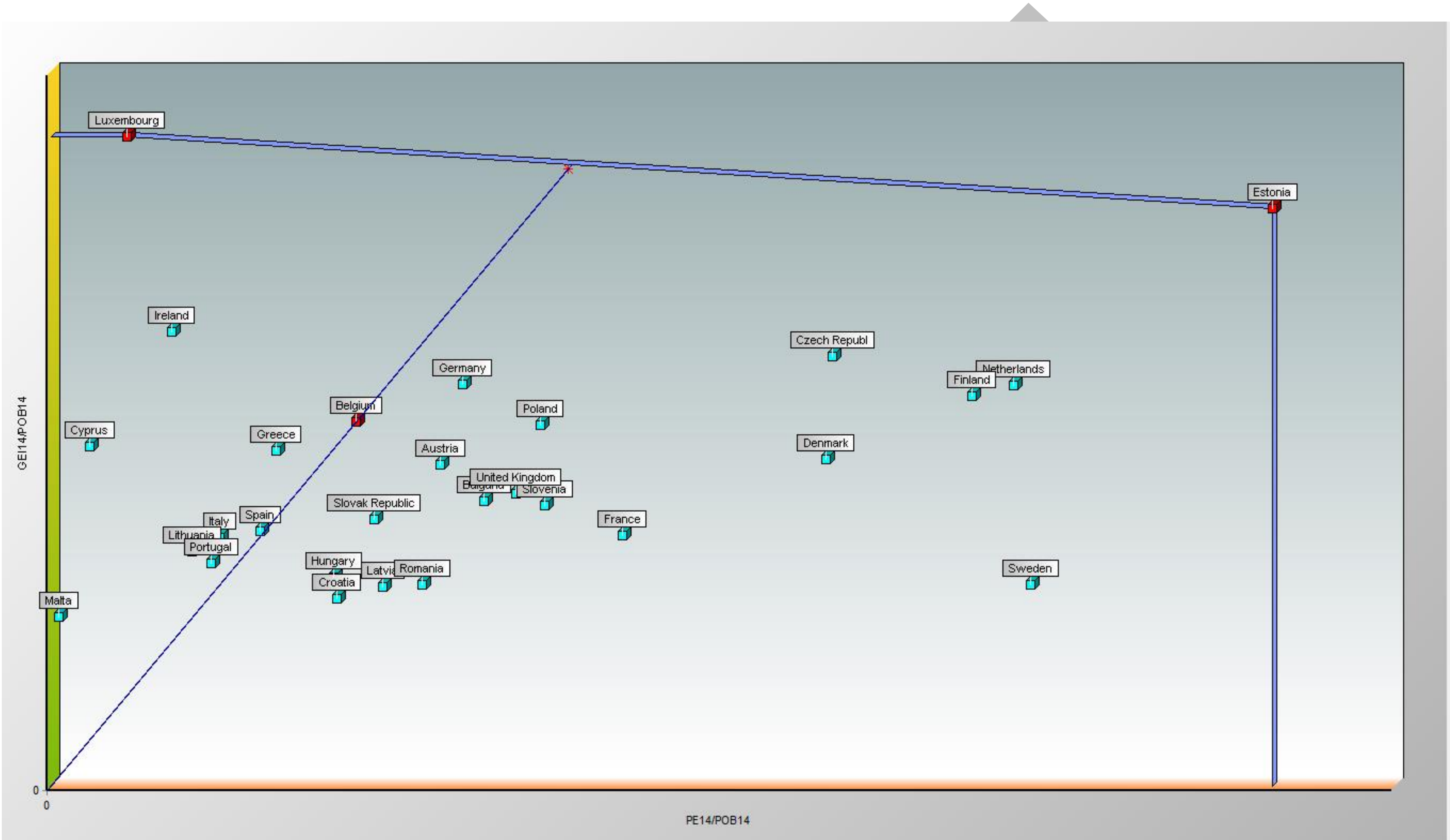
Figure II.3. Evaluation of inefficiency of the European Union in 1995, g = (GHG_0 PE_0 | P_0).



Source: own elaboration based on the data:

- Population growth (P) from the Eurostat database (2017).
- Primary energy production (PE) in thousands of tonnes of oil equivalent (TOE) from the Eurostat database (2017).
- Greenhouse gas (GHG) emissions in millions of tonnes (Mt), from the Eurostat database (2017), which includes CO_2 emissions, N_2O in CO_2 equivalent, CH_4 in CO_2 equivalent, HFC in CO_2 equivalent, PFC in CO_2 equivalent, SF_6 in CO_2 equivalent, NF_3 in CO_2 equ

Figure II.4. Evaluation of inefficiency of the European Union in 2014, g = (GHG_0 PE_0 | P_0).



Source: own elaboration based on the data:

- Population growth (P) from the Eurostat database (2017).
- Primary energy production (PE) in thousands of tonnes of oil equivalent (TOE) from the Eurostat database (2017).
- Greenhouse gas (GHG) emissions in millions of tonnes (Mt), from the Eurostat database (2017), which includes CO_2 emissions, N_2O in CO_2 equivalent, CH_4 in CO_2 equivalent, HFC in CO_2 equivalent, PFC in CO_2 equivalent, SF_6 in CO_2 equivalent, NF_3 in CO_2 equ

II.6 CONCLUSIONS

In this study, several non-parametric models of enveloping data proposed in section 4.1, were applied to analyse population growth (P) and economic growth (GDP) as two of the main pollution factors in the 28 member countries of the European Union, using data from 1990, 1995, 2000, 2005, 2010 and 2014.

Three DEA models were proposed with the aim to characterise indexes of inefficiency, subject to different inputs, translated as primary factors that influence the amount of GHG emissions and energy efficiency (translated in terms of primary energy production).

The results obtained with model (3) can be considered as a measure of the GDP-GHG decoupling level presented by the economies under study. The decoupling analysis of a country makes it possible to determine if its environmental impact mitigation strategies are sufficient or not. The decoupling evaluation carried out with this non-parametric approach can facilitate the process of formulating public policies or environmental strategies with the objective of reducing GHG emissions.

Based on the results obtained with model (3) in 2014, the countries with the best index of decoupling and greatest energy efficiency were Luxembourg, Austria, Denmark, Malta, United Kingdom and Italy. It is also notable that throughout the periods of study, a clear reduction of the indexes of inefficiency is observed, providing evidence of the probable existence of the hypothesis of the EKC in these countries.

On the other hand, model (4) turns out to be an optimal tool to evaluate the structure and activity of the population with the purpose of not only reducing greenhouse gas emissions, but also reducing energy waste.

According to the results, the majority of the members of the EU need to improve their population activity given that their indexes of inefficiency are greater than 40%. In 2014, the countries with the lowest index of inefficiency were Malta, Croatia, Latvia, Romania and Hungary.

The indexes of inefficiency reported with the two proposed models show a decreasing pattern throughout the studied periods, which would indicate an improvement in the environmental performance of the EU, which leads us to consider that the application of the 2020 strategy signed in 2010, has had favourable results, although these are minimal and the EU must reinforce its environmental policies and strategies to achieve the objectives set for 2020.

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CHAPTER III.

Evaluating the Environmental Kuznets Curve: the role of Institutions in Latin America countries

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CHAPTER III. Evaluating the Environmental Kuznets Curve: The Role of Institutions in Latin America Countries

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III.1 Abstract

The hypothesis of the environmental Kuznets curve (EKC) states that there is a non-linear relationship between economic growth and the level of pollution, where pollution will increase as it grows economically to a certain maximum where pollution will eventually tend to decline thanks to the efforts made by the increase in the income. However, this research considers that quality institutional systems can be better tools to counteract environmental damage, but in general, developing countries lack institutional quality. Therefore, the main objective of this research is to estimate the EKC from eight Latin American countries during the period 2007-2014 through generalized method of moments (GMM) models considering the CO_2 per capita as a dependent variable, and as independent variables: the GDP per capita, a democracy index, a perception of corruption index, a regulatory quality index and a political stability index. The results show that there is econometric evidence to say that the EKC hypothesis may occur in Latin America, however, in terms of the significance of the institutional variables, the variables of democracy, corruption and regulatory quality showed an incidence in the reduction of the levels of CO2 emissions. We conclude that improving the quality of institutional indexes in Latin America would have greater benefits than increasing income.

Keywords: Environmental Kuznets Curve (EKC), GMM model, CO_2 emissions, Institutional Quality, Latin America.
JEL Classification: Q56

III.2 INTRODUCTION

Environmental degradation and its relationship with economic growth have been the focal point of various international environmental policies, with the reduction of CO_2 emissions being one of the main measures to combat the problem of climate change, since these gases are responsible for more than 70% of anthropogenic greenhouse gases (IPCC, 2007).

Meadows et al. (1992), consider that economic growth, far from being a threat to the environment in the long term, seems to be a necessary evil to maintain and improve environmental quality. The same position was formulated by Grossman and Krueger (1991) who conjecture that there is a non-linear relationship between economic growth and pollution per capita, which tends to worsen as income increases until reaching a certain maximum point where finally an improvement of environmental quality is observed, this conjecture is known as the hypothesis of the environmental Kuznets curve (EKC).

It is difficult to verify that this hypothesis is manifested in poor or developing countries, such as Latin American countries, since they face the dilemma of leading their policies towards environmental conservation or economic growth. This situation is even more aggravating, because the problem of environmental quality is a by-product of the integral development of a country, where a series of economic, institutional and sociodemographic variables intervene.

According to Acemuglu et al. (2015), institutions play an important role for economic growth since they determine the incentives and limitations of economic actors. However, current economies are the reflection of a world with unusually rapid changes and that requires an institutional adaptation with the same complexity, so that the success of each economy will depend on the creation of integral institutions that not only promote efficiency in the markets, but also provide the actors with tools to combat environmental and other problems.

This is why the objective of this research is to analyze possible conditioning factors (such as economic and institutional) of the non-linear relationship that the EKC hypothesis assumes in 8 Latin American countries during the period 2007-2014, where a GMM panel data model is used to study the variables: CO_2 emissions per capita, GDP per capita, democratic index, perception of corruption index, regulatory quality index and the index of political stability.

According to the results obtained, three of the four institutional variables analyzed in this study turned out to be statistically significant (democracy, perception of corruption and regulatory quality) showing marginal effects greater than the increase in GDP per capita, indicating that according to the empirical evidence an improvement in institutional systems in Latin America would tend to reduce CO_2 emissions in a greater proportion.

This research consists of five sections, this introductory part, followed by a section that provides an up-to-date review of the EKC and the various institutional variables that influence its verification, then a third section covers the methodology and the data used in this research, followed by the discussion and results of the method applied to the 8 economies under study and finally the conclusions of the research are presented.

III.3. LITERATURE REVIEW

III.3.1 EKC hypothesis

The relationship between economic growth and its corresponding environmental effect has been widely discussed, since there are different positions in which it is stated that accelerated economic growth is one of the main causes of the decline of natural resources and environmental degradation, while its opposition states that such economic growth can be beneficial for the conservation and improvement of the quality of the environment. According to Grossman and Krueger (1991), there is an empirical relationship between per capita income and certain environmental measures, where environmental quality tends to improve as economic growth reaches a certain high level, at which point a relationship occurs where environmental quality could be represented graphically in the form of an inverted "U", which is known as the environmental Kuznets curve (EKC).

Jaffe et al. (2003) point out that in the early stages of economic growth there is a composition effect, in which it is possible that greater regulatory dispositions in environmental matters are demanded as soon as the level of income increases (Bruvoll et al. 2003). In this way, these regulations will achieve a technical effect which will favor economies to transition their highly polluting services into services with low levels of pollution (Lindmark, 2002, Turner and Hanley, 2011).

That said, it is evident that in developing countries, environmental problems are even more challenging to solve, because the adoption of development initiatives in these countries face a dilemma between directing their growth towards the increase of income or towards environmental conservation. According to Hook Law and Ibrahim (2014), in the best-case scenarios, developing countries will have to sacrifice the environmental component to pursue the full development of their economies, once this is achieved, the same economic growth will serve as a watershed to mitigate environmental degradation.

Several studies have carried out investigations that prove the central hypothesis of the EKC. Nasir and Rehman (2011), investigated the relationship between CO_2 emissions, income, energy consumption and commercial openness in Pakistan from 1997 to 2008, finding that in that country there is no evidence of the presence of the EKC in the short term, however, in the long term, according to the results of a Johansen co-integration test, it is indicated that the coefficients of all the variables are statistically significant and have expected signs, validating the hypothesis of the EKC for Pakistan. Lapinskienė et al. (2014), confirmed the presence of the EKC in 27 countries of the European Union from 1995 to 2010, using the cubic equation form to validate the hypothesis. Bölük and Mert (2015), examined the CO_2-GDP ratio considering renewable energy sources as an impact variable on the reduction of emissions in Turkey using data from 1961 to 2010, the results of the research show the existence of the hypothesis of the EKC also demonstrating that renewable energy will contribute to the improvement of environmental quality. Shahbaz et al. (2016), investigated the presence of the Kuznets curve in 19 African countries during the period 1971-2012 incorporating the variables of energy intensity and globalization within the study, the results of this research show that only Sudan and Tanzania present, in the long term, the inverted U between economic growth and CO_2 emissions. Alam et al. (2016), examined the impacts of income, energy consumption and population growth on CO_2 emissions using data for the period 1970-2012 for India, Indonesia, China and Brazil, the observations resulting from the tests imply that in the cases of Brazil, China and Indonesia, the CO_2 emissions will decrease when income has increased, while in the case of India, the increase in income over time will not reduce emissions of CO_2 in the country.

According to the observations made by these researchers, it can be deduced that the problem of environmental quality would be a by-product of development, where a series of variables also intervene, in addition to the ones already presented, which can also help to reduce pollutant emissions.

It is for this reason and in order to broaden the scope that this research focuses on analyzing the role of various institutional systems in Latin America as factors that contribute to the reduction of environmental damage caused by accelerated economic growth.

III.3.2 The role of institutions in environmental quality.

Institutions are formed to reduce the uncertainty that human exchange entails when they are directed by individual behavior (North, 2016) and according to Acemoglu et al. (2015), institutions play an important role for economic development since these determine the incentives and limitations of economic actors. However, environmental problems tend to be uncertain, in that regard, Weisbuch (2000) establishes the need to restructure or create new institutions that do not lack sufficient mechanisms to combat such problems.

On this matter, Panayotou (1997) showed that the quality of institutional systems and government policies on environmental matters, can significantly reduce environmental degradation even with low income levels and accelerate improvements to higher levels of income, so better institutions and better policies can help to flatten the EKC. However, despite these results, the role of institutions as a determining factor of environmental quality has been debated more broadly, because contradictory empirical results have been obtained.

For this reason one of the main objectives of this research is to recognize that institutional systems serve as possible key factors to reduce CO_2 emissions. And this work is an extension article of diverse investigations, considering then, that variables such as democracy, perception of corruption, regulatory quality and political stability are the possible Latin American institutions that have the greatest incidence in reducing the level of CO_2 emissions.

In related literature it has been identified that democracy has had a positive effect on environmental quality, because democracies provide economic freedom and therefore there would be markets that could promote environmental quality (Berge, 1994), as well as electoral responsibility and the ability of groups to socially mobilize making democracies more responsive to the environmental needs as opposed to autocracies (Kotov and Nikitina, 1995), likewise, democracies respect the rule of law and human life (Weiss and Jacobson, 1999). However, democratic governments are sensitive to the economic concerns of the majority of voters, so when the loss caused by the application of environmental policies is expected to be great, democracies become reluctant to alleviate environmental degradation (Hosseini and Kaneko, 2013).

The level of corruption is another variable that is considered to have an effect on environmental quality and arises from the idea that low levels of corruption imply that prosperity variables, such as income, will increase and then these will affect environmental quality causing the inverted U shape (Cole, 2007). However, this position is widely criticized as it has been shown that corruption promotes slow growth (Murphy et al., 1991). Meanwhile, Knack and Keefer (1995) establish that levels of corruption affect investment and growth.

According to Apergis and Ozturk (2015), political stability is another variable that is expected to promote environmental quality, through stable governments and without problems of violence or terrorism, since they can focus even more on compensation for environmental damage. In the same way, these authors have also established that higher levels of regulatory quality have a positive impact on the reduction of emissions, due to the increase in the promotion of environmental practices through political regulations.

In recent years the effect of various other institutional variables has been studied in different nations or in different regions. Fredriksson and Wollscheid (2007) used a propensity score method with data from the late 1990s from 163 countries to evaluate which type of democratic system has a better incidence with improvements in environmental quality, researchers concluded that parliamentary democratic systems positively affect environmental policy and that democratic systems apply a greater number of strict environmental policies than autocracies. Aubourg et al. (2008), explored a modified specification of the classic EKC, where they condition the relationship of pollution-economic growth with external debt and the degree of democratization of 29 Latin American and Caribbean countries with data from 1963 to 1999 using panel data models of fixed effects and random effects, their findings indicate that both variables are significant, implying that different political and economic contexts could serve as a strategy to reduce the carbon emissions of developing countries. Bernauer and Koubi (2009), empirically tested the existing theories on the provision of air quality, using data on sulfur dioxide (SO_2) concentrations for 107 cities in 42 countries between 1971 and 1996, the results of this investigation show that the degree of democracy has an independent positive effect on air quality and also ensures that presidential systems are more conducive to air quality than parliamentarians. Recently, Charfeddine and Mrabet (2017), used panel data to examine the role played by several macroeconomic factors, sociodemographic and institutional variables in the degradation of environmental quality in 15 MENA countries during the period 1975-2007, their empirical findings provide strong evidence that the level of democracy helps to improve the quality of the environment.

Faiz-Ur-Rehman et al. (2007), assessed corruption as a variable that affects environmental quality, finding that this variable has a negative impact on environmental protection and that the reduction of corruption has a greater effect on environmental policy in relatively closed economies, this conclusion came from the study of a group of developed and developing economies from 1983 to 2006. Jalil and Habibullah (2013), investigated the impact of the Kyoto Protocol and four institutional factors on the growth of CO_2 emissions per capita in

Asia and the Pacific regions during the 1971-2009 period, they used a generalized method of moments and discovered that the environmental policy of the Clean Development Mechanism of Kyoto and levels of corruption describe positive and statistically significant effects on CO_2 emissions. Galinato and Galinato (2012), formulated an empirical model that measures the short and long-term political stability, corruption and economic growth in CO_2 emissions from deforestation in a selected group of 22 countries in Latin America and Asia where there is a prevalence of invasion of agricultural crops on forest land during the 1990-2003 period, they found that corruption does not have significant effects on forest cover in the short term and shows persistent long-term effects. Apergis and Ozturk (2015) examined the EKC hypothesis in 14 Asian countries during the period 1990-2011, finding that corruption positively affects pollution levels, since better control of corruption tends to reduce emissions.

III.4. DATA AND METHODOLOGICAL APPROACH.

III.4.1 Data

Annual data for the period 2007-2014 of 8 Latin American economies are used to determine the relationship between environmental degradation and the determining variables, with the objective of analyzing the effect of institutional systems on the amount of CO_2 emissions from Argentina, Brazil, Chile, Colombia, Costa Rica, Mexico, Panama and Uruguay, which are the economies that generate the highest GDP per capita in Latin America and could be considered as the countries that cause the greatest environmental damage in the region.

As previously established, institutional systems serve as a basis for economic development, since they give the actors involved the power and mechanisms necessary to condition the distribution of resources within the economy (Acemoglu et. al, 2005). For this reason, the institutional variables that this study considers could have an effect on environmental degradation in Latin American countries, are: regulatory quality, political stability, democracy and perception of corruption.

Therefore, the methodological approach includes the study of a series of variables, where GDP per capita was obtained from the Monetary Fund database and is given in dollars (US) at constant 2010 prices, while from the development indicators of the World Bank were obtained the data concerning the amount of CO_2 emissions per capita given in kilo tons (kt) and also two of the institutional variables which are: regulatory quality and political stability.

The regulatory quality variable captures the perception of the government's capacity to formulate and implement policies and regulations that promote the development of the private sector (Kauffman et al., 2005). Meanwhile, the variable on political stability measures perceptions of the likelihood of political instability and / or politically motivated violence, including terrorism. The estimation of these two variables provides the scores of the countries in the aggregate indicator, in units of a standard normal distribution, that is, ranging from -2.5 to 2.5 (World Bank, 2017).

In addition, the democratic development index of Latin America (IDD, 2017) was used, which ranges from 1 to 10, with 10 being the best democratic system. The data of the index of perception of corruption was obtained from the NGO International Transparency, which goes from 1 to 10, with 10 being the indicator of the least corruption (CPI, 2017).

III.4.2 Methodological Approach.

The empirical model has been estimated through a generalized method of moments (GMM) panel data methodology (Arellano and Bond, 1991) and equation 1 shows the modeling used in this study, according to Panayotou (1997) and Aspergis et. al (2015), this type of modeling represents the functional form of the Kuznets curve, since it includes quadratic terms that associate the levels of CO_2 emissions with a series of determining factors. Additionally, this approach allows us to introduce institutional variables in an additive way with the income to capture its effect in the EKC. To consider that the environmental Kuznets curve assumption will happen $\alpha_1 > 0$ and $\alpha_2 < 0$. And to obtain the point of return of the GDP per capita (or maximum point) $y^* = \exp(-\alpha_1/2\alpha_2)$ is estimated.

$$CO_{it}^2 = \alpha_1(y_{it}) + \alpha_2(y_{it})^2 + \alpha_3(Demo_{it}) + \alpha_4(Corr_{it}) + \alpha_5(Reg_{it}) + \alpha_6(Pol_{it}) + \alpha_7 Time + \varepsilon_{it}$$

…Equation (1)

Where:

CO_{it}^2 Emissions per capita of a country i at a time t

y_{it} Gross Domestic Product per capita of a country i at a time t

$Demo_{it}$ Democracy of a country i at a time t

$Corr_{it}$ Corruption of a country i at a time t

Reg_{it} Regulatory Quality of a country i at a time t

Pol_{it} Political stability of a country i at a time t

The parameter α_{it} allows the possibility of the fixed effects of the countries, while ε_{it} indicates the estimated residuals. This GMM system incorporates instrumental variables and estimates the components of the equation in first difference and with the first lag for CO_2.

It is expected that the sign of the coefficient revealed from the variable GDP per capita *(y)* will be positive, because higher levels of per capita income are attributed to more intensive levels of production which, in turn, contribute to higher levels of emissions, although greater economic well-being leads to a greater demand for pollution reduction. In terms of the institutional indexes, *Demo* is expected to have an association that can be both positive and negative with the concentration levels of emissions, since it may be the case that democratic systems tend to improve environmental quality, similarly, the autocratic imposition of environmental legislation could also contribute to the improvement of environmental quality. It is expected that the variable that indicates the level of corruption *(Corr)* in an economy negatively affects the levels of concentration of carbon emissions, since an improvement in the level of perception of corruption leads to an improvement in the quantity of emissions. Regarding the variable on regulatory quality *(Reg)*, the sign shown is expected to be negative, since the higher the regulatory quality is, the more a decrease in the quantity of emissions would be expected. It is also expected that with greater political stability *(Pol)* in a country, the level of emissions will decrease, therefore the expected sign is negative.

III.5. DISCUSSION AND RESULTS

The fixed effects and the random effects of the model were estimated, according to the Hausman test, the fixed-effect specification has a better fit than the random effects specification. The variables show a slow change over time so it is reasonable to estimate the models that explain both the serial correlation and heteroscedasticity, however, to validate these assumptions, the Wald heteroscedasticity test and the Wooldrige autocorrelation test were applied to the models. Table 1 shows the results of the application of unit root tests for the variables under study, the results show that the null hypothesis of non-stationarity can not be rejected (at 5% significance) for all level variables. However, applying the first difference, the results of the unit root tests show that most of the level variables are stationary with a 5% significance. This finding indicates that all study variables are integrated at least in a first order.

Table III.1 Unit Root Tests

	LLC	Hadri-LM	H-T	Fisher-ADF	Fisher-PP
y	- 3.5464*	2.7866	-5.3083*	17.5274	-2.2440
Δy	-9.0860 *	-2.2099	-0.5425*	44.3158*	-8.0088*
CO_2	-3.7611*	-0.6035	-9.0590	-1.6953	-9.4203*
ΔCO_2	-7.7754*	-2.1082	-9.1421*	-4.3301*	-11.5807*
Demo	-0.3234	-0.8685	0.3889	-1.8512	-1.0884
ΔDemo	-4.8683*	4.0363*	-7.4242*	8.1586*	9.7340*
Corr	-3.8440	4.9648*	0.6396	4.3752*	-1.6341*
ΔCorr	-6.5011*	4.9648*	-0.0566 *	2.7278*	4.6145*
Reg	-19.4575*	-0.3934	-5.6366*	-13.4351*	-8.5659*
ΔReg	-53.6381*	-0.1249	-6.0545	-21.2763 *	-4.3053
Pol	-1.2228	-1.6767	-0.6715*	-2.0046*	-9.6884*
ΔPol	-6.4424*	-1.9429	-0.7642*	-4.3148*	-14.7930*

Source: own elaboration based on the data of:

- Gross domestic product per capita (y) in dollars at constant 2010 prices from the Monetary Fund database (2017)
- Emissions of CO_2 (CO_2) in kilo tonnes (kt), from the World Bank database (2017).
- Index of democratic development in Latin America (IDD, 2017).
- Index of perception of corruption (CI) of the NGO international transparency (CPI, 2017).
- Regulatory quality index from the World Bank database (2017).
- Political stability index from the World Bank database (2017).

* Significance at 5%

The results of the application of equation 1 are detailed in Table 2, in the diagnostic section some of the econometric criteria that the model satisfies are presented, additionally the test of Sargan, AR (1) and AR (2) is included. Table 3 (see Annexes) shows additional models that were tested to support that the model of equation 1 is the one with the best fit.

Table III.2 GMM estimates for CO2 emissions.

Variable	Coeficient	P> [z]
$CO_{it}^2 = \alpha_1(y_{it}) + \alpha_2(y_{it})^2 + \alpha_3(Demo_{it}) + \alpha_4(Corr_{it}) + \alpha_5(Reg_{it}) + \alpha_6(Pol_{it}) + \alpha_7 Tiempo + \varepsilon_{it}$		
$\boldsymbol{l.CO2}$	-.720494	0.000
$\boldsymbol{y}$	.00035	0.000
$\boldsymbol{y^2}$	-1.28e-08	0.002
$\boldsymbol{Demo_{it}}$	-.0418	0.057
$\boldsymbol{Corr_{it}}$	-.1911	0.032
$\boldsymbol{Reg_{it}}$	-.4834	0.003
$\boldsymbol{Pol_{it}}$	-.1601	0.483
$\boldsymbol{\_cons}$	1.3650	.043
Diagnostico		
R2	0.9584	
N	64obs	
Sargan	0.2157	
AR(1)	0.0238	
AR (2)	0.1619	

Source: own elaboration based on the data of:

- Gross domestic product per capita (y) in dollars at constant 2010 prices from the Monetary Fund database (2017)
- Emissions of CO_2 (CO_2) in kilo tonnes (kt), from the World Bank database (2017).

- Index of democratic development in Latin America (IDD, 2017).
- Index of perception of corruption (CI) of the NGO international transparency (CPI, 2017).
- Regulatory quality index from the World Bank database (2017).
- Political stability index from the World Bank database (2017).

* Significance at 5%

According to the results obtained, there is evidence of the presence of the EKC hypothesis between emissions and per capita income in the 8 Latin American economies under study, since the estimated coefficients yielded the expected signs and turned out to be statistically significant.

As shown in Table 2, the association between emissions and GDP per capita, is positive in the level variable and negative in the squared variable. The model shows a high general adjustment (R2 = .9584), which implies that our variables seem to be adequate to explain the amount of CO_2 emissions.

Regarding the institutional variables, democracy (*Demo)* is statistically significant and shows an unexpected positive, which could lead us to think that for these countries democratic systems are not efficient in reducing the amount of CO_2 emitted. The variable that measures the perception of corruption (*Corr)* turned out to be significantly positive with a sign that was not expected. The regulatory quality variable (*Reg*) turned out to be a significant variable and showed a negative sign with the largest marginal effect with respect to the other variables, which indicates that an improvement in regulatory frameworks helps to reduce the amount of CO_2 emissions. In terms of the variable *Pol*, the resulting sign was negative, however, it turned out to be a non-significant variable for the model. The point of return of income per capita according to the results is $ 393,535.75 USD.

These results can be compared with the results obtained by Aspergis et. al (2015), which establish that political stability, government effectiveness, regulatory quality and corruption are the institutional frameworks that play an important role in reducing global atmospheric emissions. Unlike the results obtained by Fredriksson et. al (2007) which, in their investigation, conclude that democratic systems impose less stringent environmental policies and therefore this variable does not turn out to be significant for their model. The results of Galinato et. al (2012) also express that the institutional variables on political stability and control of corruption are not variables that help improve environmental quality.

III.6. CONCLUSIONS

The main objective of this research was to evaluate the role of institutional quality on environmental degradation. In this process, we also investigated the validity of the EKC hypothesis in a sample of 8 Latin American countries (Argentina, Brazil, Chile, Colombia, Costa Rica, Mexico, Panama and Uruguay) for the period from 2007 to 2014. For the analysis used a generalized moments model (GMM), where CO_2 per capita was considered as the dependent variable and as independent variables were the GDP per capita, the democracy index, the perception of corruption, the regulatory quality and the political stability. This work is an extension of some research that considers institutional systems as a measure to reduce environmental degradation, however, this work focuses on the analysis of Latin American developing economies, where institutional frameworks are not always of quality.

According to the results obtained we can conclude several questions. First, we have empirical evidence to establish that the Kuznets curve hypothesis can occur in the 8 countries under study.

Secondly, we can conclude that, while the majority of existing works focus on the consequences of economic growth on environmental degradation, we show that institutional frameworks do play a positive role in the reduction of CO_2 emissions in economies in process of development. Particularly, we find that, higher levels of democracy help to achieve a decrease in the level of CO_2 emissions per capita with greater effectiveness than income, in the same way, an improvement in the level of perception of corruption helps to reduce CO_2 emissions and even when better political stability did not prove to be a significant variable in this research, an improvement in regulatory quality frameworks did and it can help to improve the quality of the environment through the establishment of environmental policies that achieve long-term benefits for the reduction of the amount of greenhouse gases emitted into the atmosphere, together with the regulatory impulse to support the development of new technologies that will lead to the transition from classic economies to economies with low fossil fuel use.

Third, our results showed that the point of return of GDP per capita of the 8 Latin American countries is extremely high, which is why we can not expect this to be a factor that helps to diminish the environmental damage that economic growth has caused, nevertheless, we observe that according to the marginal effects, focusing on improving the institutional frameworks in Latin America would help to reduce CO_2 emissions more effectively than the increase in per capita income.

Finally we conclude that it is necessary and relevant to expand the number of research focused on improving environmental quality and consider in them the analysis of various institutional variables that can give us a positive response to the aggravating situation regarding the loss of natural resources and environmental degradation that we face.

III.7 ANNEXES

Table III.3 GMM estimates for CO2 emissions.

Variable	Coeficiente	P>[z]	Variable	Coeficiente	P>[z]
$CO_{it}^2 = \alpha_1(y_{it}) + \alpha_2(y_{it})^2 + \alpha_3(Demo_{it}) + \alpha_4 Tiempo + \varepsilon_{it}$			$CO_{it}^2 = \alpha_1(y_{it}) + \alpha_2(y_{it})^2 + \alpha_3(Corr_{it}) + \alpha_4 Tiempo + \varepsilon_{it}$		
$l.CO2$	-.7434016	0.004	$l.CO2$	-2.324932	0.000
y	.0000765	0.756	y	.0002419	0.040
y^2	2.13e-08	0.026	y^2	-2.11e-09	0.657
$Demo_{it}$	-.1995153	0.000	$Corr_{it}$	.7098111	0.000
_cons	2.32044	.001	*_cons*	3.419117	.043
$CO_{it}^2 = \alpha_1(y_{it}) + \alpha_2(y_{it})^2 + \alpha_3(Reg_{it}) + \alpha_4 Tiempo + \varepsilon_{it}$			$CO_{it}^2 = \alpha_1(y_{it}) + \alpha_2(y_{it})^2 + \alpha_3(Pol_{it}) + \alpha_4 Tiempo + \varepsilon_{it}$		
$l.CO2$	-2.492974	0.000	$l.CO2$	-1.300548	0.000
y	-.0001482	0.044	y	-.0001347	0.564
y^2	6.39e-09	0.036	y^2	1.91e-08	0.040
Reg_{it}	-2.574735	0.000	Pol_{it}	-.4649507	0.000
_cons	5.652482	.043	*_cons*	3.72853	0.000
$CO_{it}^2 = \alpha_1(y_{it}) + \alpha_2(y_{it})^2 + \alpha_3(Demo_{it}) + \alpha_4(Corr_{it}) + \alpha_5 Tiempo + \varepsilon_{it}$			$CO_{it}^2 = \alpha_1(y_{it}) + \alpha_2(y_{it})^2 + \alpha_3(Demo_{it}) + \alpha_4(Corr_{it}) + \alpha_5(Reg_{it}) + \alpha_6 Tiempo + \varepsilon_{it}$		
$l.CO2$	-1.352249	0.000	$l.CO2$	-1.967705	0.000
y	.0005343	0.000	y	.0007359	0.000
y^2	-5.54e-09	0.289	y^2	-1.81e-08	0.001
$Demo_{it}$	-.2650268	0.000	$Demo_{it}$	-.0220066	0.753

$Corr_{it}$	.8334277	0.000	***$Corr_{it}$***	1.070164	0.000
_cons	3.693781	0.000	***Pol***	-1.094762	0.000
			_cons	.6610815	0.278

Source: own elaboration based on the data of:

- Gross domestic product per capita (y) in dollars at constant 2010 prices from the Monetary Fund database (2017)
- Emissions of CO_2 (CO_2) in kilo tonnes (kt), from the World Bank database (2017).
- Index of democratic development in Latin America (IDD, 2017).
- Index of perception of corruption (CI) of the NGO international transparency (CPI, 2017).
- Regulatory quality index from the World Bank database (2017).
- Political stability index from the World Bank database (2017).

* Significance at 5%

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GENERAL CONCLUSIONS

This text is a compilation of research carried out to obtain the title of Master in Environmental and Ecological Economics awarded by Universidad Veracruzana and its main objective is to study the decoupling relationship between economic growth and the degradation of the environment, specifically the damage produced by high levels of greenhouse gas emissions. In order to achieve an integral analysis of this relationship, several other factors that participate in the increase of emissions were also considered, as well as the role of institutional systems as detrimental factors of environmental damage.

In this way, in Chapter One, the decoupling status of economic growth from the amount of CO_2 emissions was analyzed through tendential observation and the analysis of the decoupling elasticity following a method proposed by Tapio (2005) in 5 of the largest economies in Latin America (Brazil, Mexico, Argentina, Colombia and Venezuela) from 1990 to 2014 . Additionally, in this research the primary factors of CO_2 emissions were identified using the disaggregated form of the Kaya Identity. The results obtained with this research can facilitate the process of formulating public policies or environmental strategies with the aim of reducing the CO_2 emissions of the countries studied, by identifying the main factors of pollution and the degree of decoupling of the economies.

According to this research only Mexico and Venezuela experienced strong decoupling states in the last period of study (2010-2014), which can mean that these countries are well directed towards the reduction of CO_2 emissions. On the other hand, Brazil, Argentina and Colombia did not present strong decoupling states in any of the study periods, and instead those countries reported states of *expansive coupling*, indicating in this way the urgent need to take environmental measures to achieve the reduction of CO_2 emissions. Additionally, according to the evidence from 1990 to 2014, the main primary factors that influence the amount of CO_2 emitted in three of the five countries under study is the energy inefficiency index, while in Argentina and Colombia the gross domestic product per capita turns out to be the highest factor of CO_2 emissions.

This thesis also establishes that in order to reduce their emissions, it is necessary to increase the generation and use of clean energies to decrease the high rates of energy inefficiency that were reported not only in the Latin American developing countries, but also in developed countries as shown in Chapter Two, where the use of a non-parametric methodology was proposed to characterize indexes of inefficiency, subject to different inputs, translated as primary factors that influence the amount of GHG emissions and energy efficiency in 28 member countries of the European Union in the periods 1990, 1995, 2000, 2005, 2010 and 2014. In this research two DEA models were proposed, the first model can be considered as a measure of the GDP-GHG decoupling level presented by the economies under study, and the second one is used as an optimal tool to evaluate the structure and activity of the population with the purpose of not only reducing greenhouse gas emissions, but also reducing energy waste.

According to the evidence provided in this investigation, the majority of EU members need to improve their population indexes given that their inefficiency rates are greater than 40%, and by 2014, the countries with the lowest inefficiency index were Malta, Croatia, Latvia, Romania and Hungary. On the other hand, by 2014 the countries with the best decoupling index and greatest energy efficiency were Luxembourg, Austria, Denmark, Malta, United Kingdom and Italy. The inefficiency indexes reported with the two proposed models show a decreasing pattern throughout the studied periods, which would indicate an improvement in the environmental performance of the members of the European Union.

According to what was established in Chapter One and Chapter Two, the need to transform traditional economies into economies that are more inclusive of the environment is imperative and this process is not easy, even for developed economies, where high economic income could be used to combat environmental damage. Nevertheless, in poor or developing countries, this situation is even more aggravating, because they face the dilemma of leading their policies towards environmental conservation or economic growth.

For that reason, Chapter Three analyzed alternative conditioning factors for the improvement of environmental quality: the institutional systems. In this chapter, the investigation was carried out through the validity of the EKC hypothesis in a sample of 8 Latin American countries (Argentina, Brazil, Chile, Colombia, Costa Rica, Mexico, Panama and Uruguay) for the period from 2007 to 2014 using a generalized moments model (GMM), where CO_2 per capita was considered as the dependent variable, and as independent variables were GDP per capita, the democracy index, corruption perception, regulatory quality and political stability.

According to the results obtained, three of the four institutional variables analyzed in this study turned out to be statistically significant (democracy, corruption perception and regulatory quality) showing marginal effects greater than the increase in GDP per capita, indicating that an improvement in institutional systems in Latin America would tend to reduce CO_2 emissions in a greater proportion than the increase of income.

The term "decoupling" was not used in the third chapter, nonetheless, this research is based on the validation of the Kuznets curve and according to Grossman and Krueger (1991), the decoupling stage would begin to be observed when growth in income reaches a stage where the relationship between this variable and environmental quality is graphically observed as an inverted "U".

The overall findings in this thesis make it possible to establish that the relationship of decoupling between economic growth and environmental degradation can be possible through the correct application of environmental policies and actions, based on specific studies to address the situation of each country. However, the participation of diverse economic agents, who can advocate for the conservation and regulation of natural resources, is also fundamental.

According to Panayotou (1997), quality of institutional systems and government policies can significantly reduce environmental degradation even with low income levels, since institutions determine the incentives and limitations of economic agents (Acemoglu et al. 2015), the same ones that can advocate for the mitigation of environmental damage.

In this way, this research also establishes the need to restore or create optimal mechanisms to improve the institutional quality in turn to provide the necessary tools to include the environment within the economic system.

It is necessary to establish that although the measurement of decoupling can serve as a good basic tool for the elaboration of public policies, the analysis of the various factors that could favor this delinking relationship is even more fundamental especially in institutional matters, where studies on how different institutional systems can affect the reduction of the environmental gap that economic growth has imposed on ecological systems, are scarce. As a final conclusion this thesis proposes that this line of research needs to be continued, considering for example, the study of the effect of diverse inclusive and extractive economic-institutional systems with the decoupling relationship between GDP and CO_2.

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