CO_2 emissions convergence among South American countries. A study of Kaya components (1980-2010).

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Abstract

This paper analyzes the convergence in CO_2 emissions per capita (CO_2 emissions over population) among ten South American countries from 1980 to 2010 based on their Kaya components [1], namely, gross domestic product (GDP) per capita, energy intensity (energy consumption over GDP) and CO_2 intensity (CO_2 emissions over energy consumption). We apply Phillips and Sul (2007) methodology [2] to tests the existence of convergence clubs in the pathway of evolution of each Kaya component. This work tries to find out whether a set of countries in the region share common convergence patterns in CO_2 emission per capita and in its driving forces. Our results show that the region, as a whole, does not present a global convergence pattern regarding CO_2 emissions per capita, however, the evidence suggests the formation of various convergence clubs for each Kaya component and the existence of two groups of countries in which there is *full Kaya convergence*, i.e,. convergence in CO_2 emissions per capita, gross domestic product per capita, energy intensity and CO_2 intensity. The first group, k_1, stands for countries with the best general economic performance, Chile and Uruguay. The second full Kaya convergence group, k_2, includes the two largest economies of the region, Argentina and Brazil, and the country which has a value in the different Kaya components closer to the regional average, Ecuador. On the other hand, only Colombia seems to show that an improvement in both energy and carbon intensity leads to the stabilization or even to the reduction of CO_2 emissions.

Keywords: CO_2 emissions, Convergence, Kaya identity, South America

1. Introduction

When evaluating the environmental, economic and social performance of regions in process of development, like South America, it is important to observe the individual behaviour as well as the behaviour, evolution and relative lags between the different economies that make up these regions, and to compare with the most advanced economies of the world. Moreover, in the current scenario of increasing global integration, the reduction of asymmetries between economies (particularly in income and resource use) should be a critical focus of attention. Often, the least developed countries are not able to take advantage of the benefits of integration process. This is an important issue because if the partners see that integration does not contribute, or it becomes an obstacle to their growth, the process loses the necessary political support for its consolidation [3].

On the other hand, the impact of economic activity on the environment, as the industrialization process, has received increasing attention from researchers, politicians, and society in general. In addition, growing concern over climate change has fuelled a rich literature devoted to studying the relationship between economic growth, industrial development and emissions [4, 5]. Along this line, some researchers have analyzed the convergence process in particular countries or at regional level, using as indicators CO_2 intensity (CO_2 emission over consumed energy) or CO_2 emissions per capita [6, 7, 8, 9, 10, 11, 12, 13] among others. Other studies have focused on identifying and quantifying the factors behind the behaviour of CO_2 emissions using different methodologies like long-run relationship [14, 15], structural decomposition approach [16, 17], as well as analyses based on the index number theory [18] or in a decomposition performed in the production theory framework [19, 20, 21].

We use the so-called Kaya identity [1] where CO_2 emissions per capita (CO_2 over population, CO2/POP) are written in terms of the product of three components, namely, income per capita (GDP over population, GPD/POP), energy intensity (energy consumption over GDP, ENR/GDP), and CO_2 intensity (CO_2 emission over energy, CO2/ENR), as it is explained section in 4.1. Note that by construction Kaya identity only provides infor-

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mation on CO_2 emissions coming from the burning of fossil fuels, but do not consider, for instance, CO_2 that comes form agriculture or deforestation.

Moreover, we consider the approach proposed by Phillips and Sul (2007) [2] to test for the existence of convergence clubs among South American countries on the pathway of evolution of CO_2 emission per capita and of its driving forces. This approach uncovers the existence of groups of countries that share common traits regarding their convergence paths and it was used by Panopoulou and Pantelidis (2009) [22] to find out convergence clubs in CO_2 emissions per capita among a group of 128 countries for the period 1960-2003. The contribution of our work to the literature on energy-emission convergence will be the area under study, most of South American countries, which is one of the biggest emerging regions in the world with a development path based on the industrialization of their economies. This study also contributes to the existing literature concerning energy consumption and emissions for the region [23, 24, 25] and to the effect of the different driving forces on emissions.

The process of convergence in per capita energy consumption and CO_2 emissions is currently a core concern for policymakers in developed economies that are currently working towards the long-run objective of achieving a fair distribution of emissions among countries[1]. The goal of this work is to study whether some countries in the region share common convergence patterns in CO_2 emission per capita and in its driving forces, or show evidence of a *full Kaya convergence* (convergence over all Kaya components and CO_2 emission per capita). To identify clubs of countries, that converge into a given level of CO_2 emissions, as well as countries which CO_2 emission levels are diverging, could be a matter of interest to policymakers helping them to design more effective energy and environmental policies.

The paper is organized as follows: Section 2 summarizes the main data indexes of the South American countries under study, Section 3 shows some insights on the convergence process of the different Kaya components, Section 4 introduces the methodology followed in this work to test the process of convergence, Section 5 summarizes and discusses the results of this work, and finally, Section 6 provides the conclusions and policy implications.

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[1]The European Union climate and energy package of 2020 proposes many measures to achieve medium-term objectives in order to reach convergence and to reduce emissions on a long-term horizon [26].

2. Overview of the study area

During the analyzed period (1980-2010)[2], the population in South America grew from 240 to 392 million. Brazil is the country with the largest population accounting for 195.2 million in 2010, followed by Colombia (46.4 million), Argentina (40.4 million), Peru (29.3 million), Venezuela (29.0 million), Chile (17.2 million), Ecuador (15.0 million), Bolivia (10.2 million), Paraguay (6.5 million) and Uruguay (3.4 million). The average annual growth rate of the population between 1980 and 2010 was 1.6%.

The region had a GDP of 3,967 billions US-2005-PPP[3] dollars (USD) in 2010 which represented 5.5% of the world GDP. Brazil is also the country with the highest GDP in the region reaching 1,968 billion USD in 2010. The country with the lowest GDP is Paraguay with 34 billion USD in 2010. From 1980 to 2010, GDP grew at an average annual rate of 4.8% in Chile, 3.5% in Colombia, 3.4% in Paraguay, 3.1% in Peru, 2.9% in Ecuador, 2.6% in both, Bolivia and Brazil, 2.5% in Argentina and 2.2% in both, Uruguay and Venezuela. However in the last decade the average growth of the region was 3.9% (1.1 times more than in the 1990s and 2.6 times than in the 1980s). The GDP per capita (GDPpc) in the region in 2010 (9,489 USD) is very close to the world GDP per capita (9,848 USD), but the region still lies within the so-called developing countries. Chile has the highest GDP per capita (14,435 USD) in 2010, followed by Argentina (12,710 USD), Uruguay (12,569 USD), Venezuela (10,894 USD), Brazil (10,079 USD), Peru (8,501 USD), Colombia (8,450 USD), Ecuador (7,692 USD), Paraguay (5,313 USD) and Bolivia (4,246 USD).

The energy intensity (energy used over income) in the region is lower than global energy intensity (184 kg of oil equivalent per 1,000 USD, kgoe/000-USD, in 2010) and has declined from its highest value 144 kgoe/000-USD in 1983 to 133 kgoe/000-USD in 2010. However the average value in the region for the analyzed period is 136 kgoe/000-USD. Venezuela is, by far, the country with the highest value in energy intensity 233 kgoe/000-USD (1980-2010), followed by Argentina (164 kgoe/000-USD), Paraguay (157 kgoe/000-USD), Chile (142 kgoe/000-USD), Bolivia (137 kgoe/000-USD), Brazil (133 kgoe/000-USD), Colombia (107 kgoe/000-USD), Ecuador (100 kgoe/000-USD), Uruguay (99 kgoe/000-USD) and Peru (87 kgoe/000-USD).

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[2]Based on the database of the World Bank 2013, http://data.worldbank.org/

[3]Purchasing power parity. An international dollar has the same purchasing power over GDP as a U.S. dollar has in the United States.

The CO_2 intensity (CO_2 over energy) in the region has remained relatively constant (2.2 kgCO2/kgoe) during the analyzed period and always below the world average (2.5 kgCO2/kgoe). Ecuador is by far, the country with the highest CO_2 intensity (3.0 kgCO2/kgoe), a value which is even higher than the world average. Venezuela is the country with the second highest CO_2 intensity (2.7 kgCO2/kgoe), followed by Argentina (2.4 kgCO2/kgoe), Bolivia, Chile, Colombia and Peru (2.3 kgCO2/kgoe), Uruguay (1.9 kgCO2/kgoe) and Paraguay (0.9 kgCO2/kgoe).

Finally, CO_2 emission per capita in the region has seen an increasing trend being 2.0 in the 1980s, 2.3 in 1990s and 2.5 tonnes in the last decade. However in the analyzed period, CO_2 emission per capita in the region (2.3 tonnes) is much lower than the world average (4.3 tonnes). Venezuela is the country with the highest CO_2 emission per capita (6.2 tonnes), being this value much higher than the world average value. Without Venezuela the CO_2 emission per capita of the region would be 1.8 tonnes. Argentina is the second country with the highest CO_2 per capita (3.8 tonnes), followed by Chile (3.0 tonnes), Ecuador (1.9 tonnes), Brazil, Colombia and Uruguay (1.6 tonnes), Peru (1.2 tonnes), Bolivia (1.1 tonnes) and Paraguay (0.6 tonnes).

3. Evidences of convergence in the region: a descriptive statistical analysis

Three concepts of convergence, namely, σ-convergence, β-convergence, and stochastic convergence appear in the classical literature when analyzing CO_2 emissions per capita among different economies. Following Barro and Sala-i-Martin (1995)[27], the σ-convergence refers to a reduction in the standard deviation of the CO_2 emission per capita among a group of countries over a given period of time. The β-convergence (also known as the catch-up effect) occurs when countries with initially lower level of CO_2 emissions per capita (in theory low-level income economies) grow faster than high-level ones (industrialized countries). The theory indicates that there is *conditional* β-convergence when economies experience β-convergence but conditional on other variables being held constant. It is said that *inconditional* β-convergence or *absolute* β-convergence exists when the growth rate of an economy declines as it approaches its steady state. σ-convergence is a kind of strong convergence, and β- convergence is a necessary condition for the σ-convergence. This means that CO_2 emissions per capita of initially low-emission countries will increase faster than in the high-emission ones,

and therefore, all countries would finally tend towards the same level of emissions.

Stochastic convergence is another widely used method. It tests whether the time series data of relative emissions per capita (the ratio of CO_2 emissions per capita of a given country and the world average level) are stationary. If the time series of CO_2 emission is characterized by a unit root, the impact of external shocks on CO_2 emissions will be permanent and CO_2 emissions per capita will be not convergent; otherwise, the data will become stationary over time and the impacts of the shocks on emissions will be temporary.

Next we will carry out a qualitative analysis of regional convergence on CO_2 emission per capita and on its driving forces by applying descriptive statistical tools: evolution of the maximum gap (range) among the countries, evolution of the dispersion of the sample (standard deviation), study of the relationship between the initial (year 1980) and the final value (year 2010) of each Kaya component in each country, and finally, study of the relationship between the initial value of each Kaya component and the growth rate for the period.

In Figure 1 we plot, as a function of time, the difference between the natural logarithm of the maximum and the minimum value of each Kaya component and country. The gap (range) for the income per capita increased from 1.12 to 1.22 during the period 1980-2010 (black squares in Figure 1a). In fact, the evolution of this gap suggests a general non-convergence pathway, but with a transitory catching-up convergence at the middle of 1990s, followed by a non-convergence path at the end of the analyzed period.

In the case of energy intensity, the gap increased from 0.69 to 1.14 during the analyzed period (red dots in Figure 1a), which suggests a non-convergence trend in the region. However, in the last decade this gap has been stabilized, suggesting that each country is reaching a steady state[4] in its energy intensity growth rate.

The gap in CO_2 intensity decreased from 1.29 to 1.10 (blue triangles in Figure 1a) which suggests a catching-up process in the region. However, since 1994 this gap also stabilized, which indicates that each country is also reaching a steady state in the value of its growth rate of CO_2 intensity in the region.

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[4]It is considered that all countries tend to converge towards a steady state, but the level of the steady state depends on the culture and preferences of individuals, institutions and tax and legal systems.

Focusing on the gap in CO_2 emission per capita, we can see that there is a decrease from 2.53 to 2.18 (cyan inverted triangles in Figure 1a) which suggests a catching-up process in the CO_2 emissions per capita in the region.
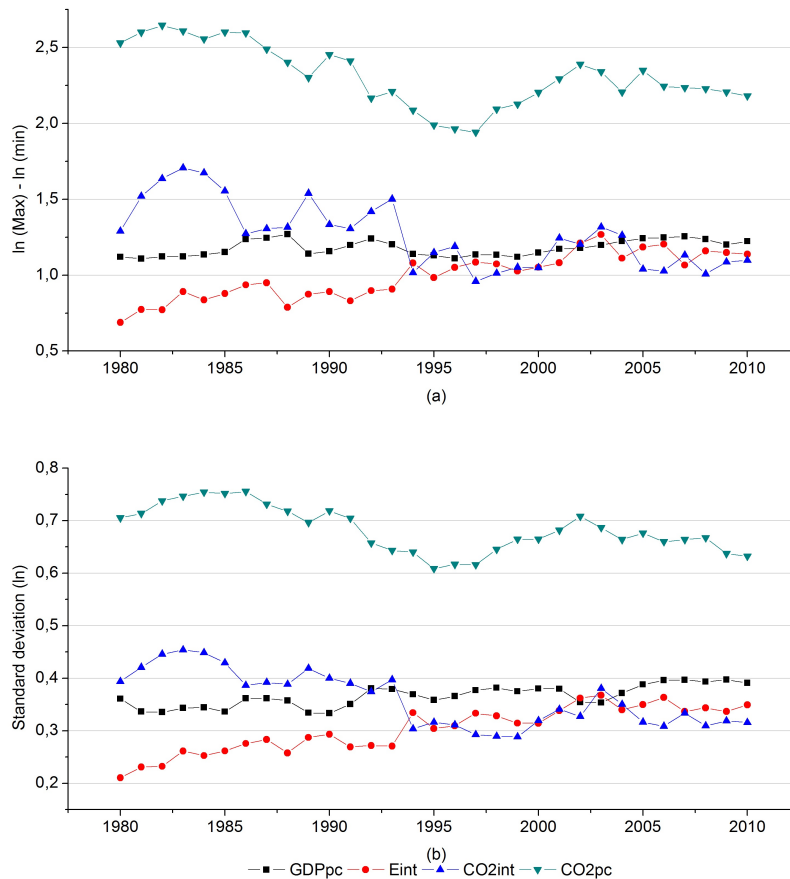

Figure 1: (a) Difference between the natural logarithm of the maximum (Max) and the minimum (min) values of the Kaya components as a function of the year. (b) Evolution of the dispersion of the Kaya components as a function of the year.

Figure 1b shows the evolution over time of the standard deviation of the natural logarithm of each Kaya component. This measurement is a proxy of σ-convergence. The evidence in the GDP per capita (black squares) shows an increasing trend (0.36 to 0.39) which indicates a non-convergence process in the analyzed period.

In the case of energy intensity (red dots) the evidence also shows an

increase in the value of the standard deviation (0.21 to 0.34), which indicates a non-convergence process in this component as stated previously. However, it is also shown a stabilization of this value in the last decade which supports that each country is also reaching a steady state in the growth rate of the energy intensity at the end of the period.

The historical data also shows a decrease (0.39 to 0.31) in the value of the standard deviation of CO_2 intensity (blue triangles), indicative of a convergence process in the region. However, it also shows a stabilization of this value since 1994 which supports that each country is reaching a steady state in the growth rate of CO_2 intensity in the region.

Focusing on the CO_2 emission per capita the evidence shows also a decrease (0.71 to 0.63) in the value of the standard deviation (cyan inverted triangles), which implies a convergence process in the region.

In Figure 2 we depict the relationship between the natural logarithm of the initial (1980) and final (2010) value of the different Kaya components. Moreover it is also plotted, as a guide, the linear regression of each set of data (note the positive slope of the lines). The figure displays a strong correlation between initial and final values, which also indicates that the value in 1980 is a good predictor of the one in 2010.

Figure 2a shows evidence of a general non-convergence process in the GDP per capita in the region. However, if we use the historical average value as a reference (blue dot), one can guess the formation of two clubs of countries: the first club has the highest value of the GDP per capita, which is also over of the world average value (Argentina, Brazil, Chile, Uruguay and Venezuela). The second club involves countries with values close to, but not greater than the world average value (Colombia, Ecuador, and Peru) and also includes countries that are still far from reaching the world average value (Bolivia and Paraguay) (see Table 1). It is interesting to note that in the analyzed period, Chile moved six places (from the seventh to the first place) and passed from the second to first group while Ecuador and Venezuela lost three positions and moved from the first to the fourth and from the fifth to the eighth place, respectively.

In the case of the energy intensity, Figure 2b shows a general non-convergence process of the region but there are hints, again using the historical average value as a reference, that support the existence of two different groups of countries and one possible outlier (see Table 1): the first club has values in 2010 between 4.80 and 5.20 (Argentina, Bolivia, Brazil, Chile, and Paraguay), the second club has the lowest values, below 4.80 in 2010
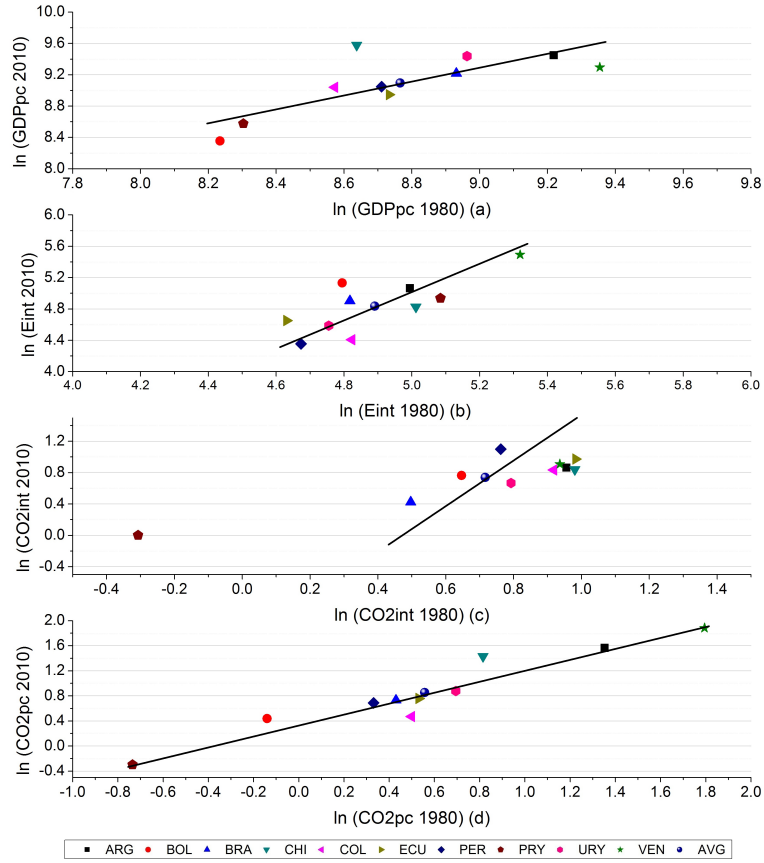
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Figure 2: Relationship between the natural logarithm of the initial (1980) and final (2010) value of (a) GDP per capita, (b) energy intensity, (c) CO_2 intensity, and (d) CO_2 emission per capita.

(Colombia, Ecuador, Peru and Uruguay). The outlier, Venezuela, has by far the highest value of energy intensity, 5.40 in 2010. It is worth to note that in the analyzed period, Bolivia shifted five places (moved from the seventh to the second place) and passed from the second to first group, increasing enormously its energy intensity in the last 30 years, while Chile and Colombia show an certain improvement and both lost three positions in the regional ranking of energy intensity.

Figure 2c shows also a general non-convergence process in the region regarding CO_2 intensity. However, once more, the evidence shows that there is a club of countries, Argentina, Chile, Colombia, Ecuador, and Venezuela,

that keeps a convergence trend for the CO_2 intensity between 1980 and 2010. This suggests similar production processes and similar technologies within industries, and the use of similar fossil fuels in these countries. The other club would consist of Bolivia, Brazil, Peru and Uruguay Note that Paraguay is a possible outlier due the role of hydro-electricity in its energy matrix (see Table 1).

In the case of CO_2 emission per capita, Figure 2d does not show a clear evidence of a total convergence, however there is some insight, using the historical average value as a reference, of convergence clubs in CO_2 emission per capita (see Table 1). The first club has the highest values (Argentina, Chile and Venezuela), the second club follows the regional average value (Bolivia, Brazil, Colombia, Ecuador, Paraguay, Peru and Uruguay).

Figure 3 shows the relationship between the natural logarithm of the initial value (1980) and the growth ratio of the period (value in 2010 over value in 1980) for each Kaya component and country. In Figure 3a, the pathway of the GDP per capita is depicted. One can see a similar growth rate for all countries in the region, regardless of their starting point, except in the case of Chile which experienced a outstanding growth and in the case of Venezuela which had symptoms of recession. However, using the regional average value as a reference (blue dot), one can distinguish two different clubs regarding the growth ratio of the GDP per capita: the first club, Chile, Colombia, Uruguay, Peru, and Paraguay, has a value of the ratio higher than the average. The second club where ratios are below the average is composed by Argentina, Bolivia, Brazil, Ecuador, and Venezuela (see Table 1).

In case of energy intensity (Figure 3b), using the regional average value as a reference (blue dot), one can distinguish two different groups regarding the growth ratios: the first club, Bolivia, Venezuela, Argentina, Brazil, and Ecuador, presents growth ratio higher than 1.00. The second club is composed by countries with a ratio lower than 1.00: Chile, Colombia, Peru, Paraguay, and Uruguay (see Table 1). Once again the formation of these clubs does not depend on the starting point of the countries.

In the case of CO_2 intensity, Figure 3c shows also two different pathways in the growth ratio of countries of the region: the first club has a growth in CO_2 intensity (Bolivia, Peru and Paraguay) above the regional average growth (1.02) and the second club presents values of growth that remain almost constant (Argentina, Brazil, Chile, Colombia, Ecuador, Uruguay, and Venezuela) and are below the regional average growth. Data suggests
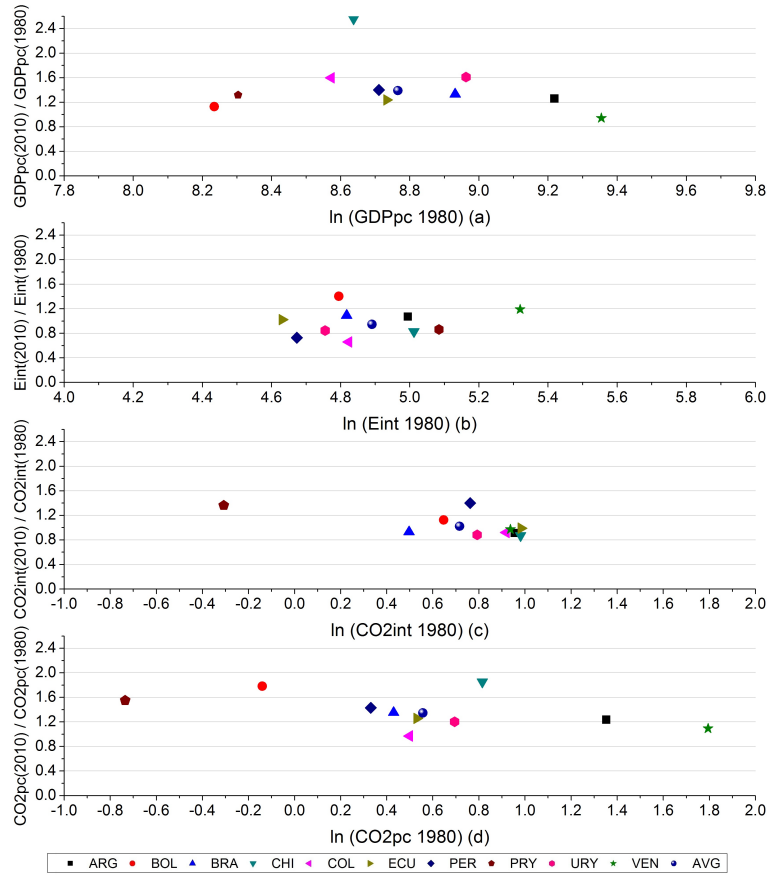
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Figure 3: Relationship between the natural logarithm of the initial value of the period (1980) and the growth rate (ratio of the final and initial value). (a) GDP per capita, (b) energy intensity, (c) CO_2 intensity, and (d) CO_2 per capita.

that countries that have managed to keep their growth almost constant, i.e., second club, are the ones that historically had the highest CO_2 intensity values (see Table 1).

Finally, Figure 3d shows two different pathways of growth in the CO_2 emission per capita: the first club is composed by countries with the highest ratios, well above the regional average 1.35 (Bolivia, Brazil, Chile, Peru and Paraguay). The second club includes countries that present a growth below the regional average (Argentina, Ecuador and Uruguay) and countries with ratios below 1.10 (Colombia and Venezuela). Once again, data suggests that the formation of these clubs do not depend on the starting point of

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the countries (see Table 1). It is important to note that Chile's economic emergence is also reflected in the level of emissions which growth, indeed, is the highest of the region.

After this qualitative analysis we can conclude that there is no clear evidence of a global convergence in the region. To find a satisfactory explanation of this phenomenon the concepts of absolute convergence and conditional or relative convergence have been introduced. The concept of steady state also is used and and when it is said that data from ten countries in South America do not show evidence of convergence, we are referring to absolute convergence criteria. The conditional convergence have to be analyzed in economies that share the same institutions and, in general, the same "steady state".

Table 1: Evidences of convergence. The reported clubs were obtained applying descriptive statistical tools. (a) Relationship between the natural logarithm of the initial (1980) and final value (2010) (see Figure 2). (b) Relationship between the natural logarithm of initial value (1980) of the period and the growth rate (2010 value over 1980 value) (see Figure3).

	GDP per capita	Energy Intensity	CO_2 intensity	CO_2 per capita
Criteria (a)	Relationship between the natural logarithm of the initial (1980) and final value (2010)			
High value Club	[ARG, BRA, CHI, URY, VEN]	[ARG, BOL, BRA, CHL, PRY]	[ARG, CHL, COL, ECU, VEN]	[ARG, CHL, VEN]
Low value Club	[BOL, COL, ECU PER, PRY]	[COL, ECU, PER URY]	[BOL, BRA, PER, URY]	[BOL, BRA, COL, ECU, PER]
Outlier		[VEN]	[PRY]	
Criteria (b)	Relationship between the natural logarithm of initial value of the period and the growth rate			
High value Club	[CHL, COL, PER, PRY, URY]	[ARG, BOL, BRA, ECU, VEN]	[BOL, PER, PRY]	[BOL, BRA, CHL, PER, PRY]
Low value Club	[ARG, BOL, BRA, ECU, VEN]	[CHL, COL, PER, PRY, URY]	[ARG, BRA, CHL, COL, ECU, URY, VEN]	[ARG, COL, ECU, URY, VEN]

Recently, a rich literature has emerged concerning the identification of convergence clubs [2, 28, 29, 30]. These studies showed that economies with similar characteristics move from a disequilibrium position to their club-specific steady state positions. Apergis et al. (2010) [31] apply the Phillips and Sul (2007) [2] clustering algorithm to explore convergence of real GDP per capita across fourteen European Union countries. Also Camarero et

al. (2013) follow Phillips and Sul (2007) prescription to study convergence in CO_2 emission over income among OECD countries over the period 1960-2008 based on its determinants, namely, energy intensity and CO_2 intensity. Below we will apply these ideas to the economies under study.

4. Methodology

We use the official dataset of World Bank [32] concerning GDP per capita (USD 2005 PPP), energy intensity (kgoe/000-USD), CO_2 intensity (kgCO2/kgoe) and CO_2 emissions per capita (tonnes) for the period 1980-2010. The study includes ten countries of South America: Argentina, Bolivia. Brazil, Chile, Colombia, Ecuador, Peru, Paraguay, Uruguay, and Venezuela. Furthermore, in order to avoid bias in favour of convergence around the GDP base year we have discarded the first 10 observations, as suggested by Phillips and Sul (2009) [33].

Using this dataset, we separately applied the Phillips and Sul (2007) [2] (PS) procedure to the CO_2 emissions per capita and to their three driving forces.

4.1. Identity methodology

The Kaya identity [1] is commonly used as an analytical tool to explore what the main driving forces are that control the amount of carbon dioxide emissions [34]. According to this identity, CO_2 emissions per capita of a given country are decomposed into the product of three components: GDP per capita (economic rent per capita of the country), energy intensity (energy consumed per unit of GDP) and CO_2 intensity (CO_2 emitted per unit of energy consumed) [35]. The identity used in this work can be written as follows:

$$CO2pc = GDPpc \times Eint \times CO2int \tag{1}$$

$$\frac{CO2}{POP} = \frac{GDP}{POP} \times \frac{ENR}{GDP} \times \frac{CO2}{ENR}, \tag{2}$$

where $CO2pc$ is CO_2 emission per capita, $GDPpc$ is GDP per capita, $Eint$ is energy intensity, and finally, $CO2int$ stands for the CO_2 intensity.

This work aims to verify whether the convergence in the evolution pathway followed by the three defined driving forces implies convergence in the pathway of CO_2 emission per capita. We will call *full Kaya convergence* to the case when there is convergence in the three driving forces ($GDPpc$, $Eint$ and $CO2int$) and in the $CO2pc$ as well.

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4.2. Econometric methodology

The PS approach for testing the Kaya components convergence hypothesis in the identification of convergence clubs is based on a non-linear time varying factor model and provides the framework for modelling the transitional dynamics as well as long-run behaviour.

This methodology is constructed on a time varying common factor representation for a set of observable series y_{it} (CO_2 emission per capita and Kaya components). Usually, y_{it} is decomposed as:

$$y_{it} = \delta_{it}\mu_t \tag{3}$$

where i stands for country and t for time, δ_{it} denotes the time varying idiosyncratic component and μ_t the common trend component, respectively. The coefficient captures the individual transition path of emissions of an economy with respect to the common steady state growth path determined by μ_t. Since δ_{it} cannot be directly estimated, PS suggested a semi-parametric form that removes the common component. In particular, they eliminate the common component, μ_t, rescaling with the panel average. They obtained next expression,

$$h_{it} = \frac{\log y_{it}}{N^{-1}\sum_{i=1}^{N}\log y_{it}} = \frac{\delta_{it}}{N^{-1}\sum_{i=1}^{N}\delta_{it}}, \tag{4}$$

where the relative parameter, h_{it}, measures the transition path relative to the panel average. In order to test the existence of convergence, PS developed a new convergence test and a panel clustering algorithm to define club convergence. The following semi-parametric model for the loading coefficients δ_{it} is assumed:

$$\delta_{it} = \delta_i + \sigma_i\xi_{it}L(t)^{-1}t^{-\alpha}, \tag{5}$$

where ξ_{it} is weakly dependent over t, but it corresponds to an independent and identically distributed function over i in the domain $(0,1)$, $i.i.d(0,1)$ in short. $L(t)$ is a slow varying function and α is the decay rate. This representation ensures that δ_{it} converge to δ_i for all values of $\alpha \geq 0$. Hence, the null hypothesis of non-convergence for some i is:

$H_0 : \delta_i = \delta$ and $\alpha{\geq}0$ while the alternative $H_a : \delta_i \neq \delta$ and $\alpha{<}0$

In order to test for relative convergence, PS run the following *logt* regression in order to test the null hypothesis of convergence,

$$\log\left(\frac{H_1}{H_t}\right) - 2\log L(t) = \hat{a} + \hat{b}\log t + u_t, \tag{6}$$

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where $H_t = N^{-1} \sum_{i=1}^{N} \left(\hat{h}_{it} - 1 \right)^2$, $\hat{h}_{it} = \frac{\log \hat{y}_{it}}{N^{-1} \sum_{i=1}^{N} \log \hat{y}_{it}}$, $L(t) = \log(t+1)$ and $\hat{b} = 2\hat{\alpha}$, where $\hat{\alpha}$ is the least squares estimate of α. The null hypothesis of convergence can be tested by applying a conventional one - sided t-test for the slope coefficient $\hat{b}$ constructed using heteroskedasticity and autocorrelation consistent (HAC) standard errors.

An important issue in the empirical convergence literature is the possible existence of multiple equilibria. In this case, the rejection of full convergence does not imply the absence of convergence in subgroups of the panel (note that full convergence refers to convergence across all South American countries). PS propose the following clustering algorithm to find a core convergence subgroup as follows:

- Order the N countries in the panel according to the value of the last observation.

- Find core members in the panel by running the *log t* regression for the k highest members with $2 \leq k \leq N$ and calculate the t-statistic t_k.

- Add one member at a time to the k core member and perform the *log t* test. If the resulting t-statistic is greater than zero, a first club is constituted.

- For the remaining members (if any) the algorithm is repeated in order to determine the next convergence club, if any other exists. This procedure terminates when the remaining countries fail to converge.

5. Empirical results and discussion

We have separately applied the PS procedure to CO_2 per capita and to its three driving forces. The results are shown in Table 2, while Figure 4 presents the transition paths. Before commenting on these results, let us note that the best performing countries are those which attain the lower values of CO_2 emission per capita, CO_2 intensity and energy intensity while the higher ones in the GDP per capita[5].

Regarding the GDP per capita, two convergence clubs were found (see Table 2). The first club, club q_1, includes Chile, Colombia and Uruguay.

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[5]Clubs q_1, e_1, i_1 and c_1 have the higher convergence value. Clubs q_2, e_2, i_2 and c_2 have the lower convergence value.
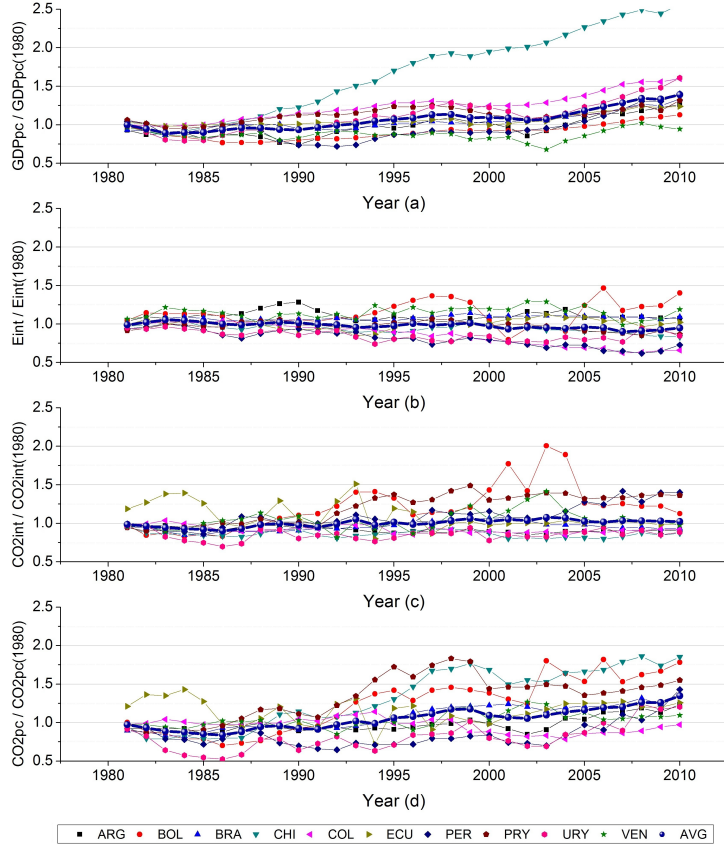
Figure 4: Transition paths for the period 1980-2010. (a) GDP per capita, (b) energy intensity, (c) CO_2 intensity, (d) CO_2 per capita (thick line corresponds to the average pathway.

The countries in this club record values greater than the region average for almost the entire analyzed period (see Figure 4a). The second club, club q_2, includes Argentina, Bolivia, Brazil, Ecuador, Peru, Paraguay and Venezuela. Therefore the first club has better economic performance than the second club. It is worth noting that the region has a general upward trend and that Chile has, by far, the best economic performance in the region (see Figure 4a).

The results regarding energy intensity also point to the existence of two clubs (see Table 2). The first one, club e_1, includes Argentina, Bolivia, Brazil, Ecuador and Venezuela. The transition paths for all the countries

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included in this club are above the regional average (see Figure 4b), meaning that in general these countries consume more energy to produce a unit of income. The countries in the second club, club e_2, are Chile, Paraguay, and Uruguay, whose transition paths are below the regional average value. Finally, two countries (Colombia and Peru) are not included in any club.

CO_2 intensity also points to the existence of two convergence clubs (see Table 2). The first one, club i_1, includes Bolivia, Peru and Paraguay. The countries in this club record values greater than the regional average for almost the entire analyzed period. The second club, club i_2, includes Argentina, Brazil, Chile, Colombia, Ecuador, Uruguay and Venezuela. However, the evidence also suggests that the regional CO_2 intensity has remained almost constant in the period under review (see Figure 4c), which looks like a poor example of environmentally friendly energy use in the region.

CO_2 emission per capita, also points to the existence of two clubs (see Table 2). The first one, club c_1, includes Argentina, Bolivia, Brazil, Chile, Ecuador, Paraguay and Uruguay. The transition paths of all the countries included in this club show an upward trend (see Figure 4d). Countries in club c_2, Colombia and Venezuela, shows a stabilization in their growth.

Finally, one an consider the so called *full Kaya convergence*, which allows as to to obtain two groups of countries, k_1, which is composed by Chile and Uruguay and k_2 formed by Argentina, Brazil, and Ecuador.

At this point, the evidence found suggests the conformation of various clubs of countries with different evolution in their Kaya components. The conformation of these different clubs as well as their relative performance in the different components needs to be nuanced (see Table 2). We should take into account the historical subgroups present in the region as a starting point. The first of these subgroups is the so called Andean countries (Bolivia, Colombia, Ecuador, Peru, and Venezuela); the second group is classified as countries of the Southern Cone (Argentina, Chile, Paraguay, and Uruguay) and finally the sub-region of Brazil.

Concerning GDP per capita and its evolution, historical evidence indicates that three of the Andean countries (Colombia, Ecuador, and Peru) show convergence and the three reach the regional average of the GDP per capita (9,489 USD) at the end of analyzed period. Moreover, as is known, Venezuela's enormous wealth of natural resources (petroleum) makes it one of the major economies in the region, with a GDP per capita higher than the world average (10,893 USD), and finally Bolivia, which has been historically the least developed country in the region, has a GDP per capita of

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Table 2: Convergence club classification. $\log t$ corresponds to twice the speed of convergence of the club towards the average. t-stat is the convergence test statistic, which is distributed as a simple one-sided t-test with a critical value of -1.65 (see Phillips and Sul, 2007 for further details).

GDPpc $\left(\frac{GDP}{POP}\right)$	Energy Intensity $\left(\frac{ENR}{GDP}\right)$	CO_2 intensity $\left(\frac{CO2}{ENR}\right)$	CO_2 per capita $\left(\frac{CO2}{POP}\right)$	Full Kaya Convergence
Club q_1	Club e_1	Club i_1	Club c_1	Group k_1
[CHL, COL, URY]	[ARG, BOL, BRA, ECU, VEN]	[BOL, PER, PRY]	[ARG, BOL, BRA, CHL, ECU, PER, PRY, URY]	[CHL, URY]
$\log t$ = -0.346	$\log t$ = -0.766	$\log t$ = 4.107	$\log t$ = 0.546	-
t-stat = -1.315	t-stat = -1.191	t-stat = 1.678	t-stat = 1.529	-
Club q_2	Club e_2	Club i_2	Club c_2	Group k_2
[ARG, BOL, BRA, ECU, PER, PRY, VEN]	[CHL, PRY, URY]	[ARG, BRA, CHL, COL, ECU, URY, VEN]	[COL, VEN]	[ARG, BRA, ECU]
$\log t$ = -0.071	$\log t$ = 2.947	$\log t$ = 3.557	$\log t$ = 1.268	-
t-stat = -0.094	t-stat = 3.087	t-stat = 4.622	t-stat = 1.334	-
-	Non-converging [COL, PER]	-	-	-

4,246 USD, which is less than half of the world average value by the end of the period (see Section 2).

Regarding the Southern Cone region, three of the countries, Chile, Argentina and Uruguay, are among the most developed economies, with higher GDP per capita in South America, leaving Brazil in fifth place after Venezuela. All these countries have a GDP per capita higher than the world average. On the other hand, Paraguay is the only country in the Southern Cone below the regional GDP per capita (5,313 USD).

With respect to the evolution of the GDP per capita, Colombia is the only Andean country located in the first convergence club (see club q_1 in Table 2) because its growth path is higher than the rest of the Andean countries (second in the region, see Figure 4a). Also included in club q_1 are Chile and Uruguay, showing that their position among the higher GDP per capita countries of the region is due to a steady growth, above the average of the region. In the second convergence club, club q_2, with a slightly slower increase (but in general with up-sloping trend) are the four Andean countries, Bolivia, Ecuador, Peru and Venezuela, two countries of

the Southern Cone, Argentina and Paraguay, and, finally, Brazil, which forms the second biggest convergence club in the region (see Table 2).

With respect to energy intensity, part on the Andean countries, Venezuela, Bolivia, and Ecuador are within the first convergence club (see club e_1 in Table 2) which have the lower performance. Ecuador is apparently the most stable Andean country because is closer to the regional average value of energy intensity (see Figure 4). Both Bolivia and Venezuela share the first position with respect to the value of energy intensity. Argentina and Brazil also belong to club e_1. The three other countries of the Southern Cone, Chile, Paraguay and Uruguay, are included in the low energy intensity club, club e_2 (see Table 2), suggesting that an improvement in energy efficiency is related with an improvement in the value of the GDP, at least in the case of Chile and Uruguay. Finally, Colombia and Peru have followed a different evolution pathway (decreasing rates of 1.3 and 0.9, respectively) than the rest of countries and they achieved better results in this regard. Table 2 show that these two countries does not belong to any of the two previous clubs.

Regarding the CO_2 intensity path, three Andean countries, Colombia, Ecuador and Venezuela, are included in the group with a slightly better yield (see club i_2 in Table 2), whose values are below the regional average in the last decade. Most countries in the Southern Cone, Argentina, Chile, and Uruguay as well as Brazil are also included in club i_2. The first convergence club, club i_1, which presents values above the regional average, includes Bolivia, Peru, and Paraguay. This evidence suggests that these countries have an older and less efficient industrial infrastructure in environmental terms (higher emissions per unit of consumed energy).

Finally, focusing on the value of CO_2 per capita, as we have already mentioned, Venezuela is by far the largest per capita emitter in the region (6.3 metric tons, see Section 2), therefore, it is very difficult for its emission rate to increase even more. The evidence indicates that relative to the growth rate of per capita emissions, club c_1 has become the biggest convergence club in the region, where eight of the ten studied countries are included (see Table 2). Club c_1 contains the economies that have experienced the larger increase in their emissions. In particular, Chile stands out because of its notorious economic emergence and Bolivia because of its ancient and still very polluting industrial machinery (see Figure 4d). Inside club c_2 are Venezuela and Colombia, which present the lower growth rate of emissions. The evidence does not show that Venezuela managed to stop

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their emissions, but it apparently reached the ceiling of this value. In the case of Colombia, it is the only country in the region where it is observed an improvement in both energy and CO_2 intensities leading to a stabilization or even reduction of emissions (see Table 2 and Figure 4).

Table 3 summarizes the results and allows observing the corresponding common convergence clubs between pair of countries for each of Kaya component.

Table 3: Common clubs between countries. q_1 and q_2 stand for the first and second club in GDP per capita, e_1 and e_2 for the first and second club in energy intensity, i_1 and i_2 for the first and second club in CO_2 intensity, and c_1 and c_2 for the first and second club in CO_2 emission per capita, respectively.

	ARG	BOL	BRA	CHL	COL	ECU	PER	PRY	URY
VEN	$q_2e_1i_2$	q_2e_1	$q_1e_1i_2$	i_1	i_1c_2	$q_2e_1i_2$	q_2	q_2	i_2
URY	i_1c_1	e_1	i_1c_1	$q_1e_2i_2c_1$	q_1i_2	i_1c_1	c_1	e_2c_1	−
PRY	q_2c_1	$q_2i_1c_1$	q_2c_1	e_2c_1	0	q_2c_1	$q_2i_1c_1$	−	−
PER	q_2c_1	$q_2i_1c_1$	q_2c_1	c_1	0	q_2c_1	−	−	−
ECU	$q_2e_1i_2c_1$	$q_2e_1c_1$	$q_2e_1i_2c_1$	i_2c_1	i_2	−	−	−	−
COL	i_2	0	i_2	q_1i_2	−	−	−	−	−
CHL	i_2c_1	c_1	i_2c_1	−	−	−	−	−	−
BRA	$q_2e_1i_2c_1$	$q_2e_1c_1$	−	−	−	−	−	−	−
BOL	$q_2e_1c_1$	−	−	−	−	−	−	−	−

6. Conclusions and policy implication

In this work we have studied the convergence process in CO_2 emissions per capita among ten South American countries from 1980 to 2010 based on the Kaya identity [1] and in its components, namely, GDP per capita, energy intensity, and CO_2 intensity. In a first approach we analyze evidences of convergence using descriptive statistical tools. These results do not show clear evidences of total convergence neither in CO_2 emission per capita nor in its driving forces (see Section 3).

As a second approach, we applied Phillips and Sul (2007) [2] methodology, which tests for the existence of convergence clubs in the pathway of evolution of the CO_2 emission per capita and of its driving forces. This work tries to provide some insight on whether a set of countries in the region share common convergence patterns in CO_2 emission per capita and in

its driving forces (see Table 3) or show evidence of a *full Kaya convergence* (convergence in CO_2 emission per capita and in its driving forces).

The obtained results also allow us to disentangle whether convergence in the evolution of the driving forces of the CO_2 emissions imply convergence in the pathway of CO_2 emissions per capita. As it is clearly showed in Tables 2 and 3, Argentina, Brazil, Ecuador, and Venezuela converge in the three Kaya components, but however only Argentina, Brazil, Ecuador converge in CO_2 per capita. On the other hand, one can find CO_2 per capita convergence without having convergence in the three Kaya components. This is the case Bolivia-Chile, Peru- Chile and Peru-Uruguay. Moreover, in Table 3 one can clearly observe the common pathways between pair of countries.

The *full Kaya convergence* (convergence over all Kaya components and CO_2 emission per capita) is reached by two groups, been the first group, k_1, composed by two members of the Southern Cone, Chile and Uruguay. These countries present the largest economic growth in the region and in turn show an improvement (reduction) in both energy and carbon intensities, although their remarkable economic growth also produces a growth of their emissions. The second group, k_2, includes three countries, Argentina, Brazil, and Ecuador, which have a moderate growth in their GDP and relatively stable energy intensity above the regional average, with a moderate reduction of CO_2 intensity (below the regional average) that results in a moderate increase of CO_2 emissions per capita. Only in Colombia exists the evidence that an improvement in both energy and carbon intensities lead to the stabilization or even to the reduction of the CO_2 emissions per capita (see Figure 4 and Table 2).

7. Acknowledgment

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