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Analysis of behaviour in the emissions of carbon dioxide of Brazil and other countries based on the Kaya Identity and the Emission Profile

Análise do comportamento das emissões de dióxido de carbono (CO2) do Brasil e de outros países por meio da Identidade de Kaya e do Perfil de Emissões

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ABSTRACT: This study analyzes the behavior of carbon dioxide emissions with regard to the economic and population growth of Brazil and other selected countries over the last two decades. We applied the Kaya Identity and the Emission Profile to model a data set related to Brazil and six other countries. The most recent data available and applied as a source of analysis during this research are from the International Energy Agency for the period 1990 to 2014. The results presented two antagonistic conclusions for Brazil. The first one is that, when comparing to the other countries under investigation, Brazil has the best position regarding the total volume of polluting gases released into the atmosphere. The second conclusion demonstrated that the carbon dioxide emissions emitted by Brazil have been growing more than the population increase. That is, if the country continues as it is, it could lose the important condition of a cleaner energy matrix.

Keywords: CO_2; GDP; decoupling; Kaya; BRICS.

RESUMO: Este trabalho analisa o comportamento das emissões de dióxido de carbono em relação ao crescimento econômico e populacional nas últimas duas décadas do Brasil e de outros países selecionados. Os métodos da Identidade de Kaya e do Perfil de Emissões foram empregados para modelar um conjunto de dados relativos ao Brasil e a outros seis países. Os dados mais recentes disponíveis e utilizados como fonte de análises no momento desta pesquisa são os da Agência Internacional de Energia para o período de 1990 a 2014. Os resultados avaliados mostraram duas conclusões antagônicas para o Brasil. A primeira é que, quando comparado aos outros países investigados, o Brasil tem a melhor posição em termos de volume total dos gases poluentes lançados na atmosfera. Já a segunda conclusão mostra que as emissões de dióxido de carbono do País estão crescendo mais do que o aumento populacional. Ou seja, se continuar da forma que está, o País poderá perder a condição de destaque de matriz energética mais sustentável.

Palavras-chave: CO_2; PIB; desacoplamento; Kaya; BRICS.

1. Introduction

The most recent data from the International Energy Agency (IEA) regarding the years 2014 and 2015 show that the values of carbon dioxide (CO_2) emissions have remained static at a global level, despite the economic growth in the same period. This is an unprecedented information that demonstrates that the beginning of the decoupling process between CO_2 emissions and economic growth is possibly occurring. According to the IEA report, a disruption of this coupling is contrary to what has always been registered among Gross Domestic Product (GDP) and global emissions of greenhouse gases (GHG) values, mainly the one of greater impact, which is CO_2 (IEA, 2016a). Similar conclusions can also be drawn based on data from the WRI (World Resource Institute) (WRI 2015; Lebling *et al*., 2018).

Preliminary information for 2015, from the last report released by the WRI (IEA, 2017b), showed that CO_2 emissions remained roughly constant at 32.1 billion tons a year since 2013. In 2014, the world GDP grew by 3.4% and, in 2015, by 3.1%, while emissions have virtually remained unchanged. Additionally, China and the US, the two largest energy consumers and also the biggest polluters of the planet, have reduced the rate of growth of their emissions, according to preliminary data from the IEA, by 1.5% and 2%, respectively. In both cases, this decrease seems to stem from new policies oriented toward industries that consume less fossil energy in favor of renewable sources (IEA, 2016b).

On the other hand, other nations are following different paths regarding the stages of economic development, population growth, and progress in less-polluting energy matrices. Thus, several researchers are currently investigating the relationships between economic and population growths and GHG emissions, more specifically CO_2. However, the emissions of other gases, such as methane (CH_4) and nitrous oxide (N_2O), must not be neglected.

For example, in two recently published papers, Conte Grand (2016) claims that, in order to avoid irreversible damage to the environment, the increase in the global temperature must not be higher than 2º C by the year 2100. Lima *et al*. (2016) links the amount of energy consumed to the socioeconomic development through an analytical approach that uses the Kaya Identity method to understand the relationships between the many variables that affect CO_2 emissions. The authors sought to generate information in order to assist decision-makers and politicians in achieving this goal through techniques that seek to identify the main reasons that originate this question. That is, the authors assessed questions related to economic expansion and changes in GHG emissions, both of which have been motivators in finding ways to better work towards the goal of achieving a cleaner planet.

Thus, two methodologies were employed in order to identify the main factors that relate to economic development and GHG emissions. The first methodology, the Kaya Identity, has been adopted by the IEA to verify to what extent different indicators impact on the level of CO_2 emissions. Through the second methodology, which proposes data modeling through an emission profile, we assessed the trajectory of a particular country over a certain period of time, in which one is able to observe how this country is releasing polluting gases in the atmosphere in relation to its economic and population growth.

Many recent papers addressing the topic were uncovered during the literature review for this study, including several that have used the Kaya Identity method. However, none of these papers have analyzed the group of countries selected in the present study.

Therefore, considering what has been presented, the goal of this work is to present an analysis of the behavior of CO_2 emissions in Brazil and other countries, such as other BRICS members and the five greatest polluters, comparative to their economic and population growth. To carry out this analysis, a group has been formed, which consisted of countries with similar patterns in their economy, population, and/or levels of GHG emissions. This analysis allows an evaluation of the comparative figures relating to CO_2 emission levels and to stages of economic development.

Thus, the present study was arranged in a specific way. In item 2, Literature Review, the state-of-the-art and some of the concepts relating to the theme are defined. The methodology for the calculation of the Identity of Kaya is found in item 3, titled Materials and Methods. Additionally, the elaboration of the emission profile, the criterion for the selection of countries and the database used are also included in this item. In item 4, an analysis of GDP and CO_2 emissions of the group of selected countries was performed. In item 5, the Kaya Identity method was used to analyze the behavior of the selected countries, taking into account factors that involve CO_2 emissions, economic growth and energy consumption. The Emission Profile of CO_2 describes the behavior of two specific relationships associated with CO_2 emissions, GDP, and population in item 6. Finally, section 7 presents the conclusions of the study.

2. Literature review

In order to make different countries adopt ways to reduce the amount of GHG released in the atmosphere, not only a governmental effort is necessary: there is also the need for an understanding of the relationships between the various factors that involve emissions. In this context, a literature review was performed to evaluate the most relevant works that discuss the subjects of economic growth, population, and energy consumption. The SCOPUS database was used as a source for searching articles, which were selected taking into account not only the number of citations, but also the proximity with the theme of this study. The main studies described here are:

Wang *et al*., (2016) show results obtained by the Kaya Identity method that suggest the decoupling of CO_2 emissions and GDP of several countries, demonstrating that economic growth without an increase in carbon dioxide emissions is not just a hypothesis, but a reality.

Dai *et al*., (2016) discuss a difference in the energy intensity of BRICS countries and of developed countries. Thus, the employment of new technologies and new policies should be strengthened in this group of countries. Lucon & Goldemberg (2009) state that energy intensity represents the energy consumption per GDP in the country. Both the energy intensity and the intensity of carbon dioxide are connected to the technology used in the addressed timeframe. Zhang & Da (2015) have conducted studies that sought to find effective means to reduce the intensity of carbon emissions (the relationship between CO_2 and GDP) in China. Generally, they concluded that the government must continue to modify their pattern of energy consumption by replacing means of greater CO_2 emission and by investing in sources that involve greater technology and that, therefore, are more efficient. This way, the energy intensity decreases, and in turn, CO2 emissions drop. A similar study was performed by Freitas & Kaneko (2011) in Brazil.

Saidi & Hammami (2015) conclude, by analyzing 58 countries, that the effect of economic growth on energy consumption is positive and significant in the global picture. In addition, they show the direct relationship between energy consumption and CO_2 emissions. Therefore, for these authors, economic growth, CO_2 emissions and energy consumption are complementary. Niu *et al*. (2011) address this very matter: the existence of a relationship between energy consumption and CO_2 emissions in 8 asian countries. Bozoklu & Yilanci (2013) and Kais & Sami (2016) also point out the connection between economic growth and CO_2 emissions.

Alvim & Santin (2008a) showed that energy consumption and energy consumption *per capita* tend to decrease with technological advances. The intensity of carbon dioxide is closely related to the energy matrix of the studied country. In his article, Fiorito (2013) comes to the same conclusions, but argues that the energy consumption to GDP ratio is not as useful to demonstrate the state of economic development of a country.

Wang *et al*. (2014) use Kaya Identity methodology along with the Tapio decoupling model (Tapio, 2005) to study the relationships between carbon dioxide emissions and economic growth. Rustemoglu & Andrés (2016) use an extension of the Kaya method to analyze CO_2 emissions related to energy consumption. Their results demonstrate, for the countries they studied, that emissions of greenhouse gases, relative to consumed energy, is an issue of great relevance.

The energy policies of some countries were changed due to the Kyoto Protocol and the Agreement of Paris, both of which aim to reduce emissions and curb climate change. Abramovay (2014) gave prominence to the duplication of the energy supply generated by renewable sources between 2008 and 2012 in some more developed countries. In the case of Brazil, Didoné *et al*. (2014) and Souza *et al*. (2015) showed that almost half of the Brazilian energy matrix is composed of renewable energy.

However, developing countries seek greater economic growth and this entails a higher energy consumption on their part. Thus, a larger and more extensive study of these new energy policies and their effects on the economy and, consequently, on emissions, should be performed. Several of the authors cited in the present study have sought to analyze the elements that originate the causes for the increase or decrease in GHG emissions. All of them, in some way, analyzed CO_2 emissions, compared them to population and economic growths and, as a result, found the reasons for the understanding of the questions related to the subject.

3. Materials and methods

This section shows the source of the data and the criterion employed to select the countries for the comparative analysis. In addition, the two methods used for the modeling of the data and how they were employed in this study are hereby described.

3.1. Data source and criteria for selection of countries

The present study was developed based on data obtained via public search in the IEA database (IEA, 2017a). The data refer to the period of 1990 to 2014, and are the most recent available data at the time of this research. The values of CO_2 emissions retrieved from this database refer exclusively to the burning of fuel.

Initially, the group of five countries that comprise the BRICS (Brazil, Russia, India, China and South Africa) were chosen because of the similarities in their economies, as displayed by O'Neill

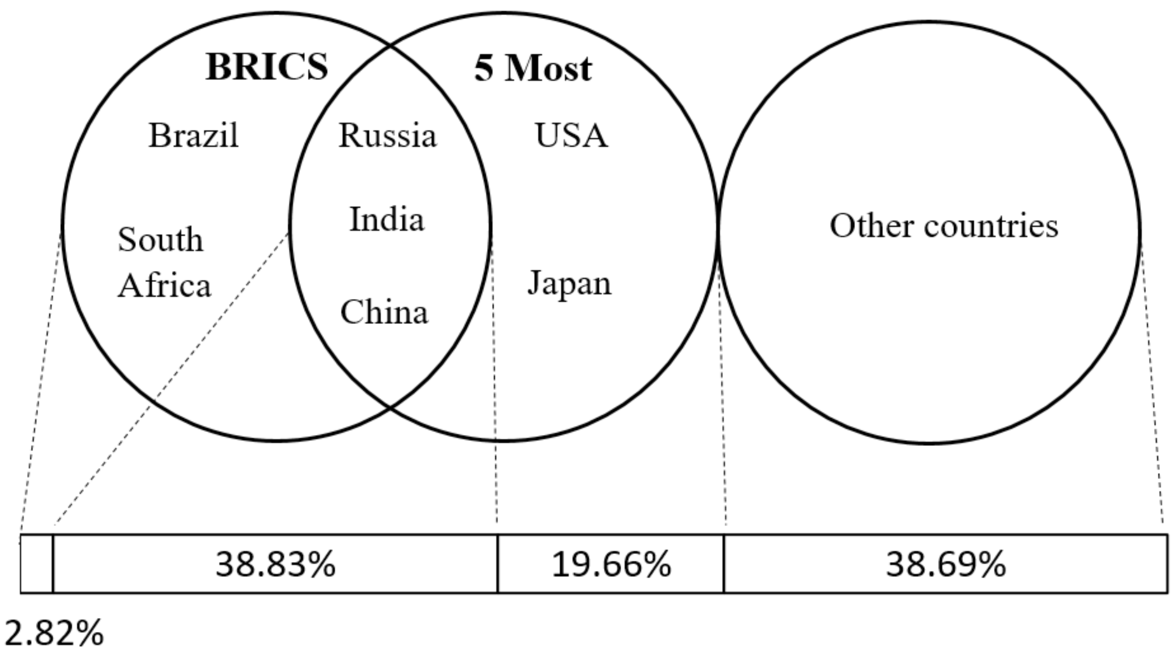


FIGURE 1 – Group of countries and involvement in CO2 emissions at a global level

SOURCE: Drafted by the authors with data from 2014. IEA data. Accessed on 02/12/2017.

(2001). Subsequently, two more countries were included: the USA and Japan. These were added to the first group because they are two of the five countries known as the largest polluters on the planet, together with Russia, India and China, which are already members of BRICS (IEA, 2017a). That is, three of the five countries that make up BRICS also belong to the group of the five largest CO_2 emitters (here named 5Most). Thus, the studied group was composed of seven countries: South Africa, Brazil, China, USA, India, Japan and Russia, as shown in Figure 1.

Figure 1 shows the respective involvement in the emissions of the chosen group of seven countries and the remaining countries of the planet. In the left circle, the BRICS group is shown. From this group, both Brazil and South Africa account for only 2.82% of global CO_2 emissions. However, the other three BRICS members (Russia, India and China) account for 38.83% of global emissions. The 5Most group is in the center circle. From this second group, USA and Japan are responsible for 19.66% of emissions. Thus, the first two circles to the left form the group of the seven countries chosen in this study (the BRICS and 5Most) which account together for 61.31% of the polluting gases in the planet. Meanwhile, the remaining countries are responsible for 38.69% of the CO_2 released into the atmosphere, that is, a little over 1/3 of total emissions.

Brazil and South Africa seem to have no similarities with the other selected countries, when compared to the 5Most. However, as shown in the present study, three of the BRICS countries, a group to which Brazil and South Africa belong, are also in the 5Most group. Hence the reason for choosing this group of countries.

3.2. IPAT and the Kaya Identity

The concept of IPAT was developed by Ehrlich *et al*. (1971). This framework, shown in Equation 1, correlates environmental impact (I) with three other factors: population (P), affluence (A), and technology (T). In this view, affluence is linked to the degree of wealth of the population, better expressed as the average consumption of each individual within the population. In terms of sustainability, this equation can connect the environment to the socioeconomic situation in order to quantify the environmental impacts of human activity (O' Mahony & Dufour, 2015).

$$I = Population\ X\ Affluence\ X\ Technolog$$

Or even:

$$I = P\ X\ A\ X\ T$$

This concept is limited by the assumption that the variables are independent among themselves and, therefore, that any eventual changes in any one of them would not affect the others (Puliafito *et al*., 2008).

IPAT, when applied to GHG emissions (Lima *et al*., 2016) is often known as the Kaya Identity (Kaya, 1989). This relation was used by Kaya, who developed a mathematical decomposition whose goal was to quantify carbon dioxide emissions in comparison with energy consumption and carbon intensity (Henriques & Borowiecki, 2014). With this feature, there is an attempt to converge to a scenario of embracing new technologies that have less pollution potential (Alvim & Santin, 2008b).

In Equation 2, we observe a decomposition of the Kaya Identity method and the equivalence with the IPAT. By comparing the latter to Equation 1, P is the population, the term or GDP per capita is represented by A, and T would be technology.

$$C = P\,x\,\underbrace{\frac{GDP}{P}}_{P}\;\underbrace{\frac{Energy}{GDP}}_{A}\;\underbrace{\frac{C}{Energy}}_{T}$$

Where:
C: Carbon dioxide emissions ($MtCO_2$);
P: Population (millions);
GDP: Gross Domestic Product (1 billion US dollars in 2010);
Energy: Primary Energy (Mtoe*).
From this, it is inferred that (Lima *et al.*, 2016):
GDP/P: GDP per capita (billions of US dollars in 2010/capita);

Energy/GDP: Energy intensity (toe/thousand US dollars in 2010);

C/Energy: Carbonic Intensity of Energy (tCO_2/toe).

Considering:

*toe: tonne of oil equivalent.

This methodology brings along the concept that the variation in the values of these indicators of CO_2 emissions is closely related to the variation of population, energy intensity, carbon dioxide intensity, and economic growth (Budzianowski, 2013). From these indicators, a base year (1990) is established, to which all other indicators can be compared. Thus, each value found can be compared to that of 1990, through a simple ratio of the value in the current year divided by that of the 1990s. This result is an index that shows the percentage variation of each aspect present in the Kaya Identity method.

In addition, the ascending or descending behavior of the curves can be verified. This behavior indicates the relative position of the country at a particular moment in time in relation to the base year 1990 (index = 1).

We reiterate that the analysis developed in this study comprised the period of 1990 to 2014, the last available values in the database of the IEA.

3.3. CO_2 emissions profile

The CO_2 Emissions Profile is a model that can be built based on a dataset in order to find a trajectory relative to the behavior of indicators of interest. This model relates CO_2 emissions to economic and population growth to a specific period of time.

The first indicator is obtained through the ratio between CO_2 emissions and the number of inhabitants (CO_2/POP), and named CO_2 emission per capita. The second indicator is obtained through the ratio between emissions and GDP (CO_2/GDP), hence named intensity of emission of CO_2. The curve, which is built up over time by the intersection of these two indicators, is known as the CO_2 Emissions Profile.

The CO_2 emission per capita is given in tons of CO_2 ($tonCO_2$) and the emission intensity of CO_2 is given in Mton per US dollars, related to the year 2010 (Mton/$).

In other words, the Profile of Emissions demonstrates how far a given country is within a temporal trajectory, that is, whether it releases more or less pollution in relation to its development and the increase in population. Additionally, the following can be stated: when the trajectory of the values described in the graph tends towards the origin of the axes (0,0), it indicates that a country is experiencing an increase in population and economic growth greater than the increase in CO_2 emissions during the period. This is what all countries should do to achieve a more clean energy matrix, in other words, to employ for the greater part renewable sources for power generation. Thus, this mechanism can be used to verify the decarbonization of energy sources within a particular country.

4. CO_2 GDP Relation

The CO_2 GDP relation is a direct comparison that can be performed to evaluate the participation percentage of CO_2 emissions compared to the size of a particular country's economy. Ideally, a country must have a greater percentage contribution to the economy than to CO_2 emissions.

4.1. BRICS share in CO_2 emissions and GDP

Figure 2 includes BRICS members and their shares in GDP and in CO_2 emissions. By adding up

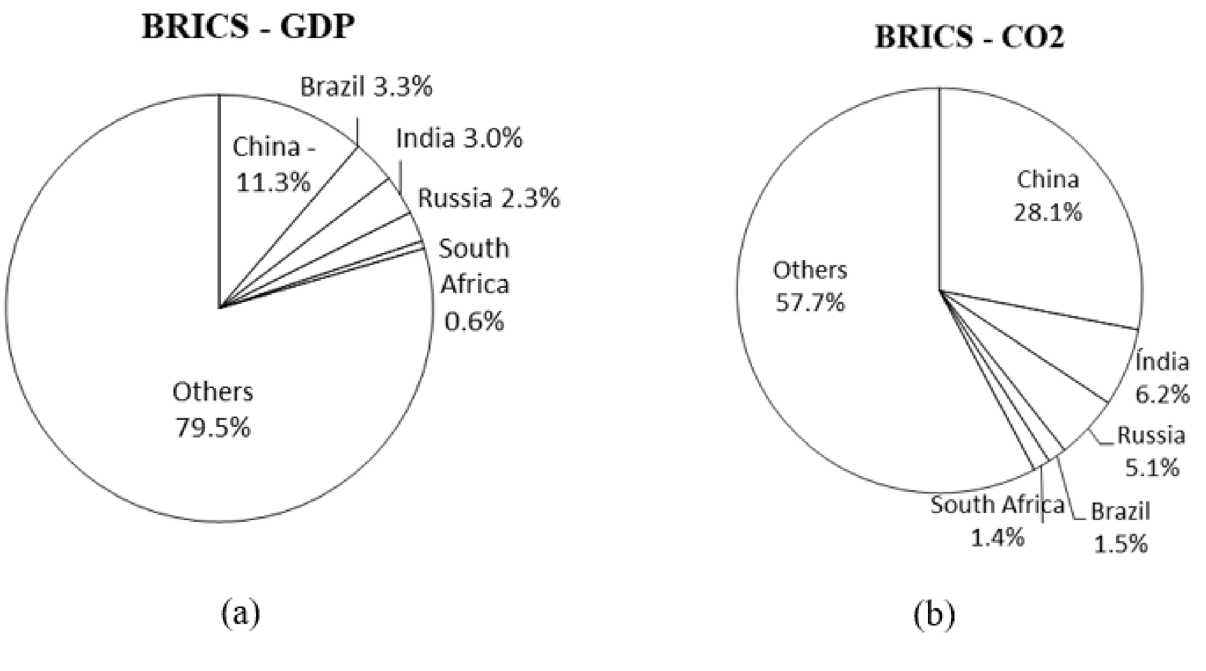


FIGURE 2 – BRICS Participation in World GDP and CO_2 emissions, (a) GDP and (b) CO_2
SOURCE: Drafted by the authors with data from 2014. IEA data, accessed on 02/12/2017.

the BRICS members GDP (Figure 2(a)), a total of 20.5% is obtained, while the other countries add up to 79.5%. China alone accounts for 11.3% of the 20.5% of the BRICS GDP, and this amount is equivalent to 55.1% of the countries' GDP. As for CO_2 emissions (Figure 2(b)), the BRICS members are responsible for 42.3% of total emissions, once again due to China's share of 28.1% of emissions within the BRICS.

4.2. Participation of the 5 largest CO_2 emitters and their GDP

Similar to Figure 2, Figure 3 shows the group of countries members of the 5Most and their shares in GDP and in CO_2 emissions. The total GDP of the 5Most, shown in Figure 3(a), is of 46.5%, while the rest of the other countries add up of 53.5%. The US and China account for 33.5% of the world GDP. As

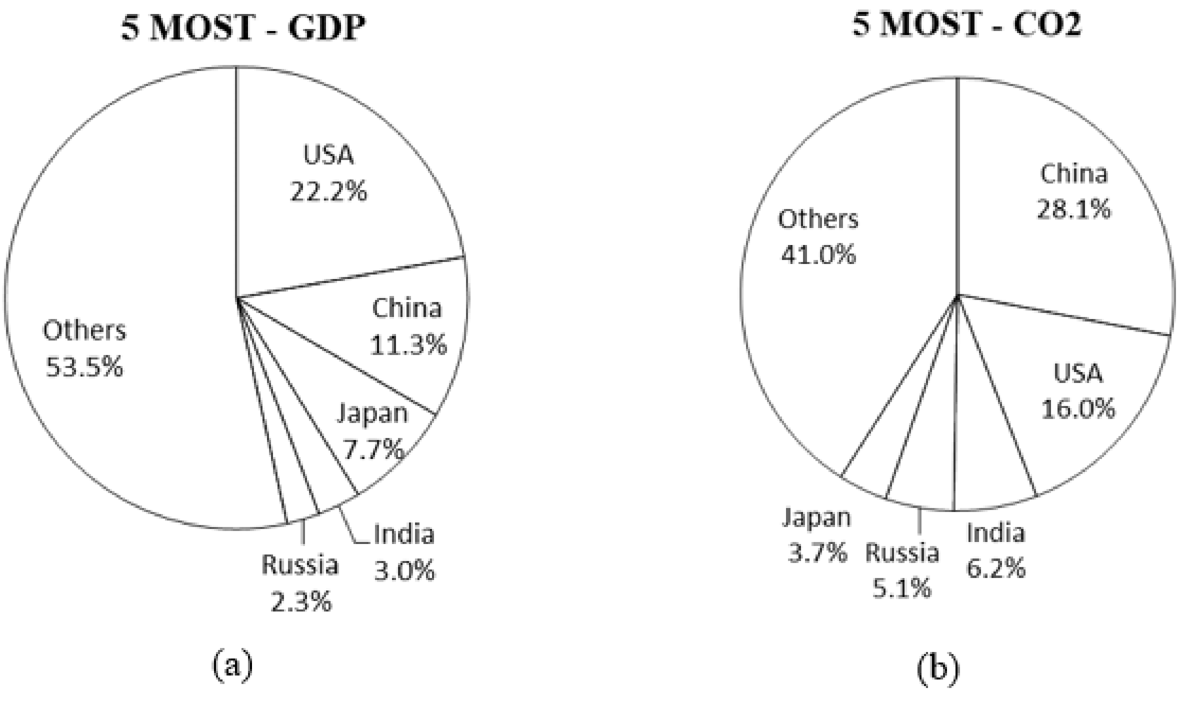


FIGURE 3 – Participation of the countries 5Most in World GDP and in CO_2 emissions in comparison to other countries, (a) GDP and (b) CO_2.
SOURCE: Drafted by the authors with IEA data from 2014, accessed on 12/02/2017.

for emissions, Figure 3(b) presents the 5Most, who are responsible for 59% of CO_2 emissions, being the USA and China responsible for 44.1% of emissions altogether, or almost half of total emissions.

By comparing the shares in economy and in CO_2 emissions between different countries, we notice an imbalance between these values. Some countries pollute more than the size of their economies, and vice-versa. The next item addresses this comparison.

4.3. Comparison of the groups

Table 1 displays the CO_2/GDP ratio. The two groups of countries, BRICS and 5Most, participate in a greater percentage share of CO_2 than that of the GDP, 2.06:1 and 1.27:1, respectively. However, when looking at each of the seven countries individually, only three of them have a CO_2/GDP ratio lower than 1. They are: Brazil, Japan, and the USA (0.45:1, 0.72:1 and 0.48:1 respectively). The remaining countries, Russia, India, China and South Africa, have a ratio greater than 1, indicating that their share of CO_2 emissions is greater than the percentage size of their economy.

TABLE 1 – Comparison between the percentage participations of the groups.

	BRICS	5MOST	BRAZIL	RUSSIA	INDIA	CHINA	SOUTH AFRICA	USA	JAPAN
gdp	20.5%	46.5%	3.3%	2.3%	3%	11.3%	0.6%	22.2%	7,7%
CO_2	42.3%	59.0%	1.5%	5.1%	6.2%	28.1%	1.4%	16%	3,7%
RATIO	2.06:1	1.27:1	0.45:1	2.21:1	2.06:1	2:48:1	2.33:1	0.72:1	0,48:1

SOURCE: Prepared by the authors. IEA data. Accessed on 02/12/2017.

The CO_2/GDP ratio is a good way to tell if a given country's participation in the economy is higher or lower than its CO_2 emissions. This information, however, is static and does not inform the nature of the economic transition to a more or less polluting matrix. This analysis can be done through the Kaya Identity and the Emission Profile, presented next.

5. Analysis from the Kaya Identity

5.1. Kaya Identity for the BRICS countries

An analysis of the BRICS by applying the Kaya Identity method showed that the six countries featured in Figure 4 do not have a standard behavior.

On the other hand, it revealed a relationship between CO_2 emissions and energy consumption. Except for Russia, the BRICS did not show a significant decrease in energy intensity.

Figure 4(a) shows the Kaya Identity method for Brazil. It demonstrates the strong relationship between energy consumption and CO_2 emissions: they both rose steadily for the most part of the considered period. The financial crisis of 2008 had a remarkable impact on energy consumption and CO_2 emissions (Brasil, 2017). Another important issue is the distance between the rates of primary energy in the period from 2010 to 2014 (2010: 1,895 / 2014: 2,162) and per capita GDP (2010: 1,406 / 2014: 1,474), with a possible separation of these two

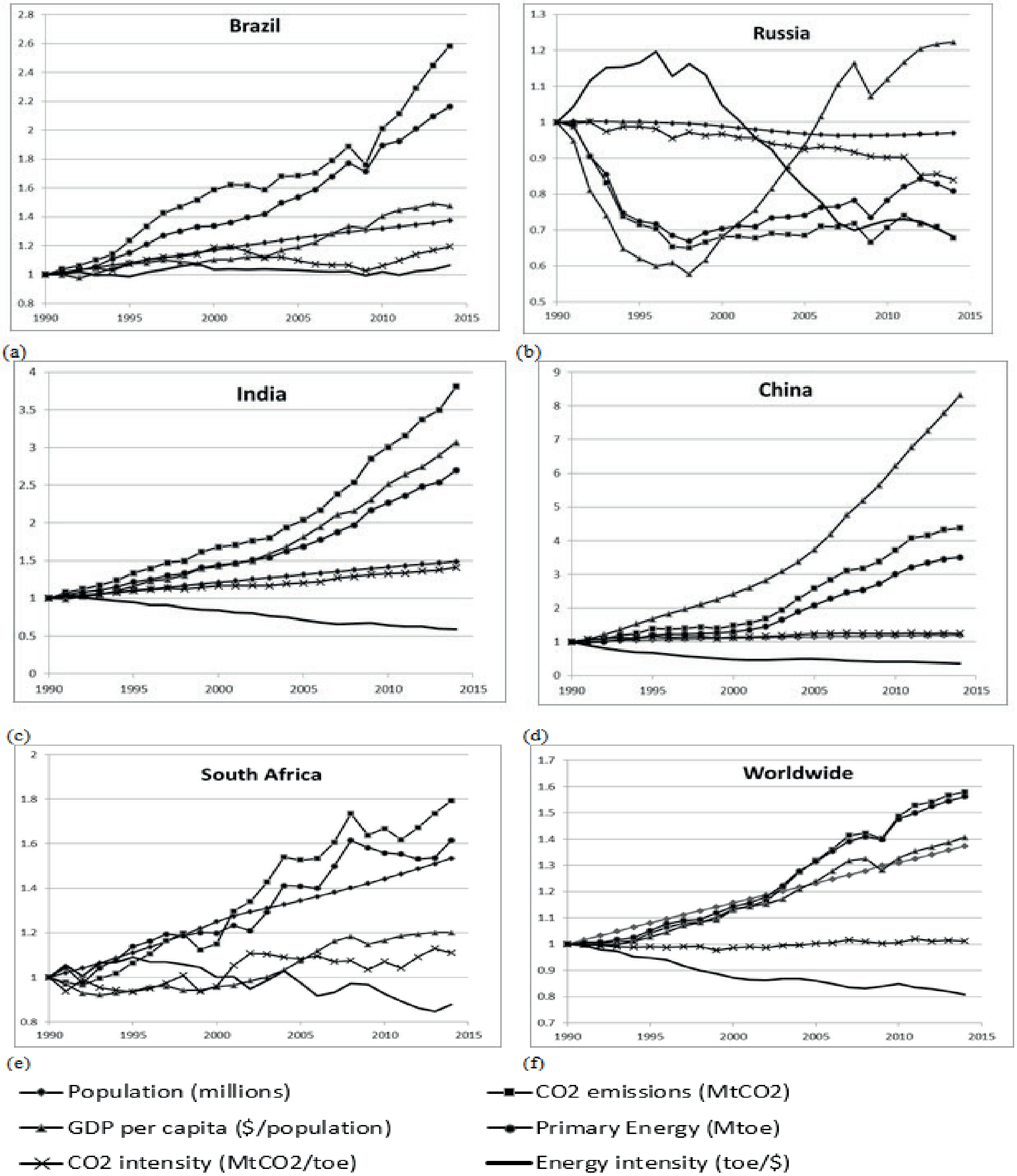


FIGURE 4 – Development of Kaya Rates for the BRICS, (a) Brazil, (b) Russia, (c) India, (d) China, (e) South Africa, and (f) Worldwide. SOURCE: Prepared by the authors with data from the IEA, accessed on 02/12/2017.

indicators considering the increase of energy intensity. The figure also shows the increase in emissions over the last few years. This can be explained by the water crisis that Brazil has been experiencing, leading to the use of thermoelectric plants, which are more polluting, in the generation of energy.

Regarding Russia, Figure 4 showed a significant decrease in primary energy consumption, CO_2 emissions, and per capita GDP. There was a recovery only in the early 2000s, demonstrated by the increase in per capita GDP and the decrease in energy intensity. In recent years, there has been a downward trend in CO_2 emissions and energy intensity. Russia, however, does not show a pattern of behavior, which is probably due to political issues the country has been facing since the end of the Soviet Union. On the other hand, it is the only country showing a decrease in CO_2 emissions, primary energy consumption, and CO_2 intensity.

India (Figure 4), on the other hand, had an increase of 280% in CO_2 emissions (1990: 1 and 2014: 3.80). This growth was accompanied by an increase in per capita GDP and energy consumption, while energy intensity decreased by approximately 41% (1990: 1 and 2014: 0.59), with a decrease in relative energy consumption. That is, there is a likely influence of new technologies applied to the production of energy through renewable and clean sources and an expansion of the service sector (India, 2017).

China (Figure 4(d)) also shows a large increase of 338% in CO_2 emissions (1990: 1 and 2014: 4.38). What stands out the most is the increase of approximately 900% in the GDP with no significant population growth (about 20%), which leads to a significant per capita GDP increase of around 730%. It is worth noting the 250% increase in the country's energy consumption, as shown by the primary energy curve.

South Africa (Figure 4(e)) shows a major increase in CO_2 emissions (80%), primary energy consumption (61%), and population (53%). The country had the highest population growth, slightly higher than India, whose population increased by 49%. Compared to other countries of the group, the behavior of the indices of South Africa has a less defined pattern. All factors show some discontinuity, although most rates tend to increase.

Worldwide Kaya rates (Figure 4 (f)) show the interdependence of CO_2 emissions and energy consumption (Primary Energy), which is represented by the almost complete overlap of the corresponding curves.

In general, the worldwide energy production is equivalent to the global CO_2 production. The decrease in energy intensity is also positive, as it indicates a GDP growth greater than the increase in energy consumption in percentage terms. Per capita GDP growth, despite the increase of population, shows an overall improvement in household economy.

5.2. Kaya Identity for the 5Most Countries

According to IEA data for the period from 1990 to 2014, three of the five most CO_2-emitting countries are in the BRICS group. They are Russia, India, and China, whose emission rates have already been discussed here. Figure 5 shows only the Kaya rates for the US and Japan.

The US (Figure 5(a)) shows a steep decrease in energy intensity, falling by 35% (1990: 1 and 2014: 0.65), and a decrease of about 7% in CO_2 intensity (1990: 1 and 2014: 0.93). This decrease is due to the country's leading role in developing and applying new technologies, which leads to cleaner and more sustainable energy generation (Lenox & Loughlin, 2017). The US, however, is still a major CO_2 emitter, which has increased in recent years, along with the country's energy consumption and per capita GDP.

Japan (Figure 5(b)), on the other hand, increased its primary energy consumption and CO_2 emissions until approximately 2004. The energy intensity decreased by 19% from 1990 to 2014 (1990: 1 and 2014: 0.81), with an especially sharper decrease from 2010 on. The economic crisis of 2008 also had a large impact on this, as shown by the decrease in per capita GDP, energy consumption, and CO_2 emissions in that year. Also evident is the increase in CO_2 intensity from 2011, mainly due to the Fukushima Daiichi nuclear disaster, and the consequent substitution of nuclear energy for other forms of energy that emit more CO_2 into the atmosphere while generating the same amount of energy (KWh) (Taghizadeh-Hesary *et al*., 2017).

6. Profile of CO_2 emission

The profile of CO_2 emission shows the patterns of CO_2 emission intensity and per capita CO_2 emission. The profile is presented in two types of graphs: bubble graph and scatter graph (IEA, 2017a).

The bubble graphs show the values of the beginning (1990) and end (2014) of the analyzed period. In addition, according to the size of the bubble, the bubble graph has the advantage of showing CO_2 emissions of both analyzed years.

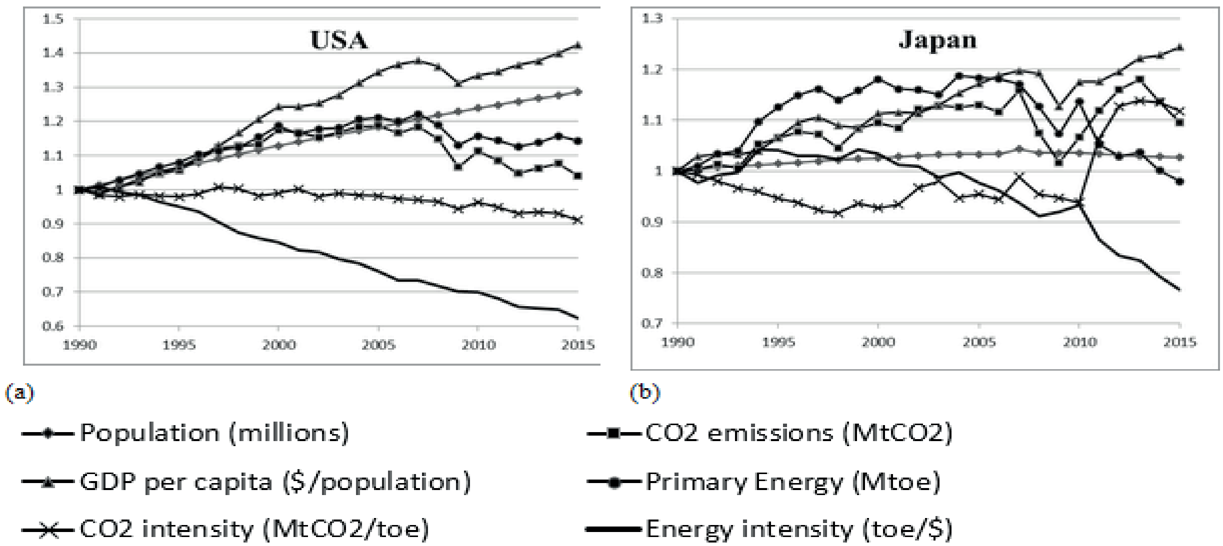


FIGURE 5 – Development of the Kaya Rates for (a) US and (b) Japan.
SOURCE: Prepared by the authors. IEA data, accessed on 02/12/2017.

The arrows indicate the direction in relation to the vertex of the axes. It should be emphasized that the arrow should point towards the vertex (0.0), as it indicates the reduction of CO_2 emission and per capita emissions.

The scatter graphs show the behavior in each year over the considered period.

6.1. BRICS

Figure 6 illustrates the CO_2 emission intensity for BRICS and worldwide. Table 2, in turn, shows in detail the data described in Figure 6 and shows the percentage variation between the initial (1990) and final (2014) years and the total CO_2 emissions.

Only Russia is moving in the ideal direction, with a negative variation in all indicators, including total CO_2 emissions.

China shows a significant decrease in emission intensity (-56.17%), but it has increased per capita emissions in 264.13% and total CO_2 emissions in 337.73%.

South Africa and India improved their CO_2 emission intensity indicator (-2.65% and -16.51%, respectively), but their CO_2 emission rates have been on the rise, with India increasing by 51.06% and South Africa by 16.93%.

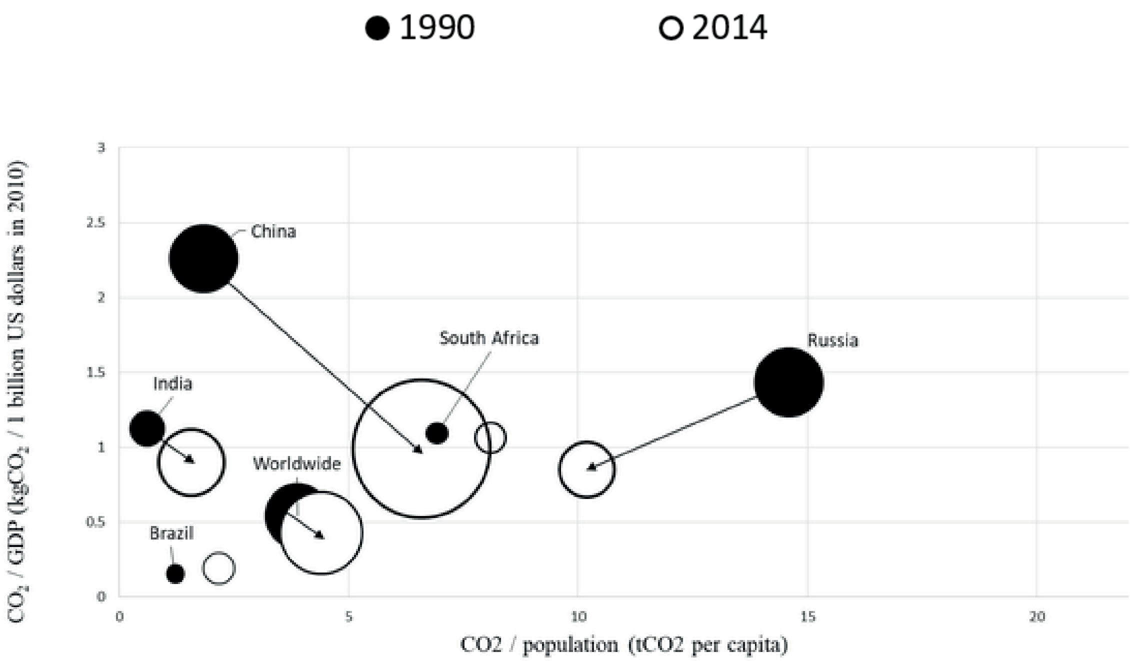


FIGURE 6 – CO2 emission intensity for the BRICS and worldwide.

SOURCE: Prepared by the authors with data from the IEA, accessed on 02/12/2017.

* Worldwide emissions divided by 10 for better graphic visualization of bubble size.

The variation of total emissions is even more significant, with India emitting 280.78% more CO_2 and South Africa 79.38% more.

Brazil exhibits behavior contrary to that desired, increasing per capita emissions and CO_2 intensity (27.10% and 87.84%, respectively). In addition, CO_2 emissions increased by 58.35%. However, the country is still well placed due to the numerical values of emission intensity and per capita emissions as well as a CO_2 emission of 476.02 Mton. This situation may be because, according to data from the Ministry of Mines and Energy, renewable energy still accounts for more than 42% of the Brazilian energy matrix (Brazil, 2017). Brazil is the only BRICS country where there has been an increase in the intensity of CO_2 emissions, which is highly unwanted.

Worldwide decrease in intensity was -18.23%, with an increase in the other two indicators, 14.98% in per capita emissions and 57.94% in total emissions.

Figure 7 presents the detailed behavior of the CO_2 emissions in relation to the BRICS countries and worldwide from 1990 to 2014. It is important to notice that the scale of each of the graphs is adjusted to the values close to the trajectory described in FIGURE 6.

Figure 7 (a) shows in detail that CO_2 emissions in Brazil present increase of both indicators (per capita and total emissions), as already indicated in Figure 6. From 1990 to 2001, Brazil showed an increase in both per capita CO_2 emissions and CO_2 emissions per billion dollars of GDP. From 2001 to 2008, the country started to perform better, maintaining per capita CO_2 emissions and reducing emissions when compared to the GDP. From 2009 onwards, this behavior was similar to that of the 1990s, with an increase in per capita CO_2 emissions and in the amount of CO_2 emitted for a given portion of GDP, both returning to levels similar to those of the 2000s. In this period, CO_2 emissions skyrocketed from 184.25 Mton in 1990 to 476.02 Mton in 2014, an increase of 58.35%. Per capita CO_2 emissions

TABLE 2 – CO2 emission intensity by the BRICS and worldwide.

	Intensity of CO_2 emission (CO_2/PIB) [$mtco_2$ / $]			**Per capita emission (CO_2/POP) [$_TCO_2$]**			**Per capita CO_2 emissions [tco_2]**		
	1990	**2014**	**Δ (%)**	**1990**	**2014**	**Δ (%)**	**1990**	**2014**	**Δ (%)**
Brazil	0.155	0.197	27.10	1.225	2.301	87.84	184.25	476.02	58.35
Russia	1.530	0.875	-42.81	14.588	10.204	-30.05	2163.23	1467.55	-32.16
India	1.102	0.920	-16.51	0.609	0.920	51.06	530.41	2019.67	280.78
China	2.519	1.104	-56.17	1.829	6.660	264.13	2075.9	9086.96	337.73
South Africa	1.093	1.064	-2.65	6.927	8.100	16.93	243.82	437.37	79.38
Worldwide	0.543	0.444	-18.23	3.885	4.467	14.98	20502.53	32381.04	57.94

SOURCE: Prepared by the authors with data from the IEA, accessed on 02/12/2017.

jumped from 1.22 tCO_2 to 2.30 tCO_2, while the CO_2 emission intensity rose from 0.15 $MtCO_2$/$ to 0.19 $MtCO_2$/$.

Between 1990 and 1998, after the dissolution of the Soviet Union, Russia (Figure 7(b)) saw a significant decline in per capita emissions, probably due to problems that arose from that transition. The indicator of CO_2 emissions per GDP increased by around 13% during the same period. From 1998 to 2008, this trend reversed with an increase of approximately 14% in per capita CO_2 emissions and a sharp reduction of about 44% in the CO_2/GDP indicator. From 2009 onwards, both indicators varied continuously, either increasing or decreasing. In this time frame, carbon dioxide emissions decreased from 2163.23 Mton in 1990 to 1467.55 in 2014.

India (Figure 7(c)) and China (Figure 7(d)) also experienced a decrease in carbon dioxide emissions. In both cases, the general trend is a significant increase in per capita emissions, mainly in China, and a decrease in the indicator of CO_2 emission intensity (CO_2/GDP). China, from 1990 to 2014, was one of the countries with the highest growth in emissions, going from 2075.90 Mton to 9087 Mton. India also saw a large increase, from 530.41 Mton in 1990 to 2019.7 in 2014.

Figure 7(e) shows that South Africa has undergone significant changes in the trajectory of the data from year to year. In the last three years, the overall trend is an increase in both indicators: that country's emissions went from 243.82 Mton in 1990 to 437.37 Mton in 2014.

In general terms, Figure 7(f) reveals that worldwide behavior is not ideal. There was a decrease in the intensity of CO_2 emissions but, contrary to what was desired, per capita emissions increased. From 1990 to 1994, there were welcome reductions in both CO_2 per capita emissions and CO_2 emissions per billion dollar of GDP. In 1995 and 1996, despite the decline in the CO_2/GDP ratio, per capita emissions started to rise again. Then, from 1997 to 1999, both indicators decreased. This changed in 2000, with per capita CO_2 emissions increasing until 2007, while the CO_2/GDP ratio remained practically constant. In 2008 and 2009, there was a new decrease in per capita CO_2 emissions. In 2010 and 2011, however, it rose again, which was followed by a new decrease of both indicators that lasted until 2014. Per capita CO_2 emissions stayed constant, while the CO_2/GDP indicator dropped.

6.2. 5Most CO_2-emitting countries

Figure 8 details CO_2 emissions of the 5 largest CO_2-emitting countries from 1990 to 2014. Table 3 presents data for the US and Japan from what was shown in Figure 8, with the percentage change between 1990 and 2014 and total CO_2 emissions.

The figure shows the US moving towards the vertex (0.0), which indicates that, although still high, per capita emission and CO_2 emission intensity are both decreasing. However, CO_2 emissions increased by 7.68% in absolute terms. Japan, in turn, experienced a small improvement in the CO_2/GDP indicator (-7.83%), although per capita CO_2 and total CO_2 emissions increased (by 11.07% and 14.22%, respectively).

Figure 9 shows the behavior of CO_2 emissions in more detail.

The US (Figure 9(a)) showed an increasing tendency in per capita CO_2 emissions until the mid-2000s while GDP rose more than CO_2 emissions, which led to a drop in the CO_2/GDP ratio throughout the period. From the other half of the 2000s on, the country began

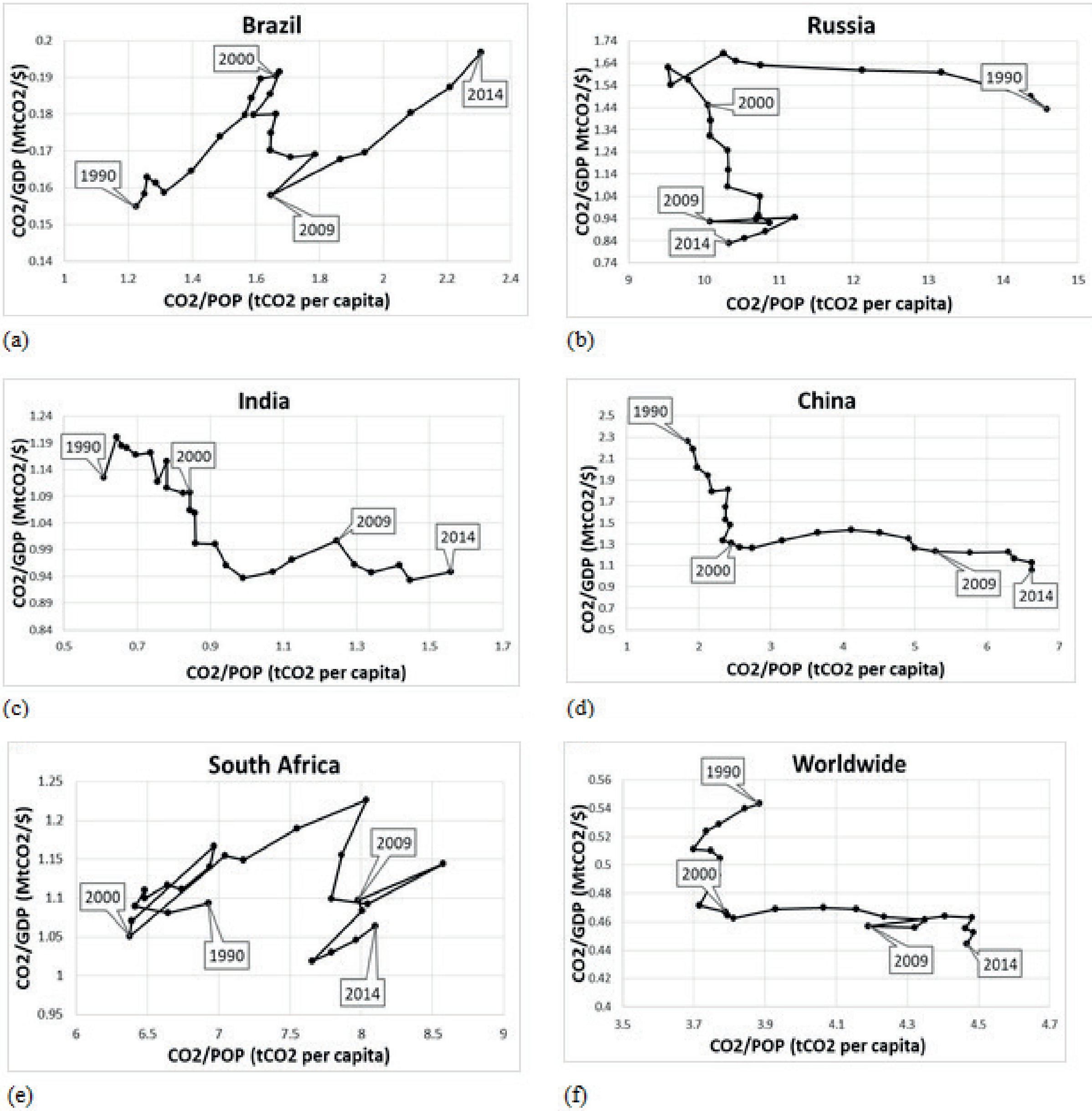


FIGURE 7 – CO2 Emissions for BRICS and Worldwide. (a) Brazil, (b) Russia, (c) India, (d) China, (e) South Africa, and (f) Worldwide.
SOURCE: Prepared by the authors with data from the IEA, accessed on 02/12/2017.

to improve even more, consistently decreasing in per capita CO_2 emissions.

In the case of Japan (Figure 9(b)), there was a tendency for per capita CO_2 emissions to increase up to 2003, while CO_2 emissions in relation to GDP remained roughly constant. From that point until 2009, both indicators decreased, pointing to an evolution towards more sustainable practices, with the country not only emitting less CO_2 per person but also increasing its GDP more than its CO_2 emissions. After 2009, probably due to the global economic crisis that took place that year, the per capita CO_2 indicator rose again, as could be gauged in 2010. In the following year, there was an increase not only in the per capita emission indicator but also in the CO_2/GDP ratio. That was due to the substitution of nuclear energy for alternative energy sources after the Fukushima Daiichi nuclear disaster. This trend continued until 2013, and it was only in 2014 that both indicators started to decrease again.

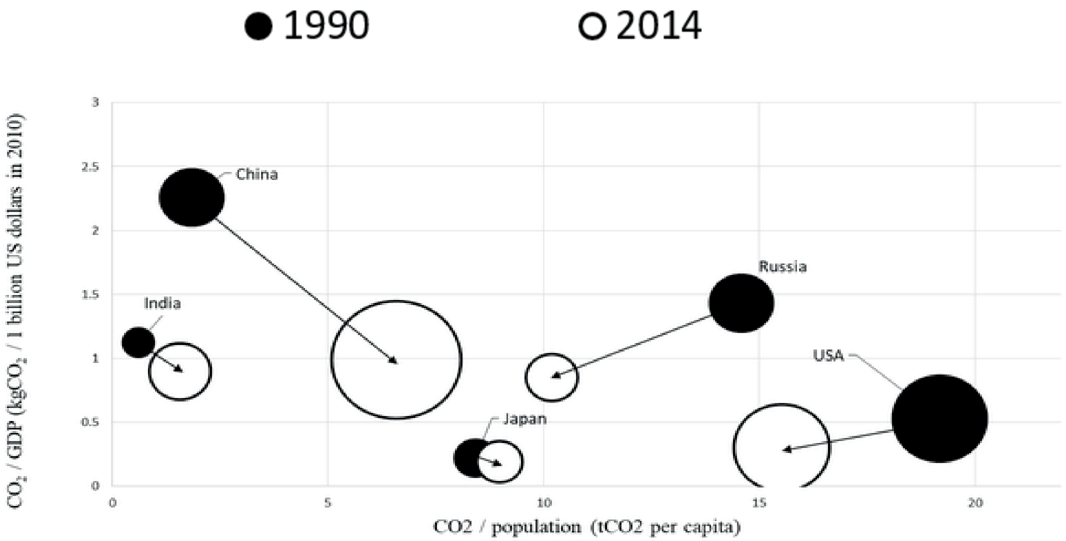
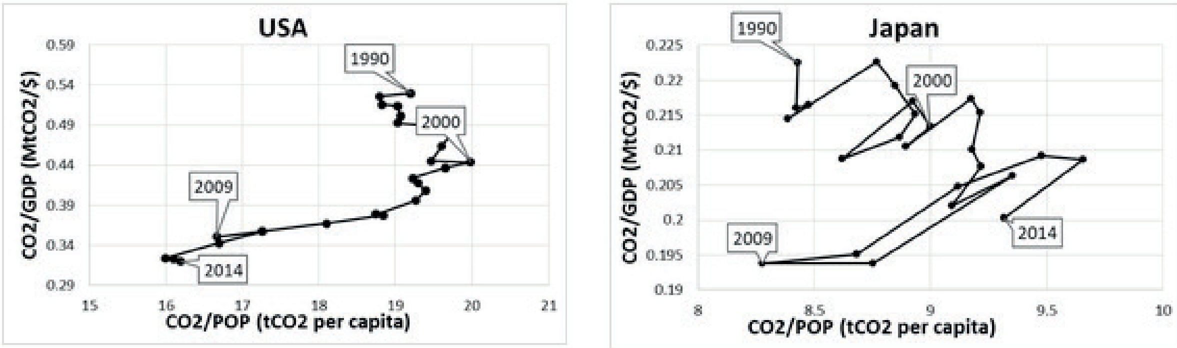


FIGURE 8 – Intensity of CO2 emission for the 5 largest CO2-emitting countries.
SOURCE: Prepared by the authors with data from the IEA, accessed on 02/12/2017.

TABLE 3 – Intensity of CO2 emission for the 5 largest CO2-emitting countries.

	Intensity of CO_2 emission (CO_2/PIB) [$mtco_2$ / \$]			**Per capita emission (CO_2/POP) [tCO_2]**			**Per capita CO_2 emission [tco_2]**		
	1990	2014	Δ (%)	1990	2014	Δ (%)	1990	2014	Δ (%)
USA	0.53	0.32	-39.58	19.213	16.221	-15.57	4806.776	5176.21	7.68
JAPAN	0.228	0.210	-7.83	8.418	9.35	11.07	2163.23	1467.55	14.22

SOURCE: Prepared by the authors with data from the IEA, accessed on 02/12/2017.



(a) (b)

FIGURE 9 – History of CO2 emission intensity for (a) the US and (b) Japan.

SOURCE: Prepared by the authors with data from the IEA, accessed on 02/12/2017.

7. Conclusion

The present work presented an analysis of the behavior of CO_2, GDP, energy consumption and other related indicators for two groups of countries, the BRICS and the 5 largest CO_2 emitting countries. Some correlations could be established, such as the interdependence between primary energy, economic growth and CO_2 emissions between 1990 and 2014 (the latest data available by the time this study was conducted).

The results obtained in this work identified an undesirable trajectory for Brazil in the evaluated period: this country's CO_2 emissions have increased more than its energy consumption, which led to an increase in CO_2 intensity. This is occurring despite this country being part of international treaties in favor of a decrease in emissions of CO_2.

On the other hand, the results for the US show that they have sought a more sustainable path, with a decrease of about 35% in energy intensity and of 40% in CO_2 intensity from 1990 to 2014, despite of remaining one of the most CO_2 emitting countries in the world.

China also shows a decrease (of 57%) in CO_2 emission intensity. This shows that the country is emitting less CO_2 for a given amount of energy. In addition, China increased its CO_2 emissions by more than 300% in the wake of the country's great economic growth in the last decades.

This article also presented and discussed other relevant results regarding the other studied countries. We have also found that, despite its contribution to our results, the Kaya Identity method has some limitations. For instance, it does not distinguish CO_2 emissions coming from fossil fuel from those emitted from renewable sources. In addition, it does not include sources such as nuclear energy. Thus, as a suggestion for future work, the Kaya method could encompass other sources of energy and separate the various sources of carbon dioxide.

The results seem to indicate that the considered countries are converging to a common value around a midpoint with respect to CO_2 emission intensity. In this context, Brazil is heading towards a relatively worse position, considering the amount of gases released into the atmosphere and population and economic growth. This seems to be a good starting point to expand research on the topic.

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