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Globalization and the shifting centers of gravity of world's human dynamics: Implications for sustainability

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ABSTRACT

World's human dynamics can be parameterized with metrics that explain the current model of economic growth and its sustainability. Changes in the world's human dynamics are crucial for understanding the current state of the world, which is faced with increasing challenges related to globalization. In this paper, we propose to analyze the shifting locations of centers of gravity of four basic global indicators (these are *Gross Domestic Product*, *carbon dioxide* emissions, population, and urban population) for the period 1960–2016. The spatial locations of the respective centers of gravity (one per year) draw some traces that explain, at least partially, relevant changes on different world's human dynamics at a global level. These traces and dynamics are further discussed. In addition, these traces are fundamental for predicting upcoming trends for the next few years. Results shown here may help political leaders and policymakers for solving upcoming and future global challenges related to the current economic system and its impact on the environment.

1. Introduction

The current era of *economic globalization* explains how national territories are dissolving (Hirst et al., 2015). The economic perspective is essential for understanding the concept of *globalization* in the broadest sense. Hirst and Thompson (1996) argue that the global economy is dominated by uncontrollable market forces, mostly truly transnational corporations that are located on wherever the globe market advantages dictate. However, the *globalization* process refers not only to the economic dimension, but also some political, cultural and environmental ones (Eriksen, 2014). In fact, there is no consensus on how *globalization* can be defined. Al-Rodhan (2006) attempted to provide a comprehensive overview of the most accepted definitions of this concept, suggesting the next agreed-upon one: “*Globalization is a process that encompasses the causes, course, and consequences of transnational and transcultural integration of human and non-human activities*”. Larsson (2001) referred to the process of world shrinkage, distances getting shorter, and things moving closer, while Robertson (1992) pointed to the intensification of the consciousness of the world as a whole. Both Paul (2005) and Giddens (1991) referred to the extension and intensification of social relationships across world-space. Held et al. (1999) referred to the widening, deepening and speeding up of the global interconnection. There are also some criticisms with regard to the extensive use of this concept. Some authors agree that the current economy is *highly internationalized* and mostly concentrated in the Triad of Europe, Japan/East Asia, and North America. However, genuine transnational companies appear to be relatively rare. For this reason, these authors are skeptical of using the concept of *globalization* (Hirst et al., 2015). These perspectives indicate that “although there is no agreement on what globalization is, the entire discourse on globalization is founded on a quite solid agreement on that globalization is” (Bartelson, 2000).

Beyond the discussion on what *globalization* essentially means, it is quite evident that the globalization process has turned the world to be more dynamic than ever before. From the economic perspective, developing countries like China and India have experienced an unprecedented growth rate over the last three decades

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because of the global restructuring of manufacturing industries. Driven by the globalization process, it has been common for transnational companies headquartered in developed countries to move their manufacturing sections to developing countries where they can benefit from lower labor costs, cheaper land prices, and the almost non-existent environmental awareness. This was possible because of the rearrangement and reinforcement of transport systems around the world, which implies a different perception of the geographical space (Balsa-Barreiro et al., 2019; Li and Phelps, 2019). This high connectivity facilitates closer proximity between goods and people, which promotes an increase in opportunities and wealth by expanding potential markets (Pentland, 2014). One of the consequences of economic globalization is the redistribution of wealth across the world with developing countries accounting for a greater share of the world economy, a fact that has been recently documented by studies such as Quah (2011) and Grether and Mathys (2010).

In addition to the realignment of the world economy, the process of economic globalization results in the global redistribution of energy demands, population, and especially the urban population, which actually relates to the other dimensions of globalization such as the environmental and social ones (Eriksen, 2014). The compensation for economic growth relates to the high demands on energy and, by extension, on the environment. The most evident is the ecological price of economic growth. For instance, Toth and Szigeti (2016) analyzed the correlation between *Gross Domestic Product* (GDP) and the ecological footprint, while Figge et al. (2017) studied the effects of globalization on ecological footprints. From a global perspective, there has been a significant rise in energy demand across the world and, especially in developing countries where faster economic growth is usually associated with lower energy efficiency. For instance, by analyzing the coupling/decoupling of economic growth from energy demand in China and India, Wang et al. (2019) found that both countries have generally shown a weak decoupling state between 1990 and 2015. In fact, China has only achieved some progress in terms of decoupling in most recent years, while India's efforts towards decoupling have been unsatisfactory. This indicates that developing countries could have generated carbon dioxide (CO_2) at a faster growth rate than developed countries over the last few decades (Ward and Mahowald, 2014).

Another consequence of economic globalization relates to the spatial redistribution of the world's population and, in particular, urban population. The balance between *population and resources* in traditional rural societies was altered since the Industrial Revolution in Europe (Balsa-Barreiro, 2011). Cities became industrial hubs with most of the job opportunities. Thus, it was started an urbanization process in today's developed countries as they went industrialized. Nowadays, developing countries are replicating these same dynamics, living a massive rural exodus that is leading to an exponential growth of their cities. This episode of massive urbanization is not new, but it is its magnitude and speed (Zlotnik, 2017). Therefore, the process in developing economies is leading to today's urban shift, which is unprecedented in scale and speed. This does not take place in an orderly and gradual way such happened in western countries in the past. Instead, the concentration of people, goods, and services in cities has led to an uneven relationship between urban population and wealth. By analyzing the quantitative weight of the 2600 largest global cities, Dobbs and Remes (2012) found that these cities collectively concentrated 38% of the world's population, but 72% of the global GDP. However, it is also true that rapid urbanization involves important adverse effects such as the huge ecological footprint due to a large amount of both resources required and pollutants emitted (Wiedmann et al., 2015).

On balance, the globalization process has led to a redistribution of wealth, people, energy demands, etc. that also contributes to the emergence of some new inequalities. Some of them have been studied at certain territorial scales, but hardly ever at a global level. For this reason, a *macro-scale* analysis describing a big picture of an uneven world is necessary.

The *center of gravity* is a helpful estimator for assessing some of the redistribution trends caused by globalization. This is represented as a point that shows the average location of a weighted object. Over the years, it has been widely adopted by scholars as a simple, but helpful metric, for mapping the uneven level of development among countries. In one of the first studies, Hilgard (1872) used it for detecting trend changes in the distribution of population in the United States. More recent studies were focused on the spatial changes followed by the world's economic center of gravity (Quah, 2011), emphasizing the recent displacement from somewhere in the Atlantic Ocean towards Asia (Grether and Mathys, 2010). The center of gravity is also considered for evaluating other factors and dynamics. Thus, Zhang et al. (2015) studied the eastward shift of the world's center of gravity of global scientific production since the 1950s. Kharas and Gertz (2010) argued that the center of gravity related with global energy consumption, which has been so far concentrated in the OECD countries, is expected to shift towards Asia by 2020 because of the upcoming growth of Asian middle classes. Zhang et al. (2018) carried out a spatial econometric analysis for assessing how population and land urbanization are affecting carbon dioxide (CO_2) emissions in China.

Mapping the *center of gravity* for the most relevant indicators related with wealth, environment, population and urbanization can offer meaningful insights for better understanding the redistribution trends that have taken place (and will continue to take place) driven by the globalization process. In this paper, we analyze the global shift of centers of gravity related to the *Gross Domestic Product* (GDP), carbon dioxide (CO_2) emissions, overall population, and urban population during the period 1960–2016.

The remainder of this paper is structured as follows. Section 2 presents the work methodology. Section 3 shows the results, which are analyzed and discussed in section 4. Section 5 discusses some policy implications. Finally, section 6 summarizes the main points and presents the conclusions.

2. Methodology

Data related with GDP, carbon dioxide (CO_2) emissions, total population, and urban population are extracted from the World Bank (2016) for the period between the year 1960 and 2016 (2014 in the case of CO_2 emissions). These data are collected at the country level.

These indicators are mapped by country and year. Each country is represented by a node, which corresponds to the political capital. Because this study covers a large period, we considered all the changes in the borders of countries. For this reason, some of the nodes were added/removed depending on the year census. Countries of the same continent are represented with the same color palette for the whole period. The size of the node depends on the quantitative value of the indicator shown (Fig. 1).

Depending on the weight of each indicator, we estimate one global center of gravity for each indicator and/or year. This metric allows the spatially weighted center to be identified. In total, 56 nodes (one per year) are estimated for each indicator by considering the whole period. By drawing the traces described by these nodes, we reconstruct the spatial pattern of displacement for each indicator over the whole period.

Several methodologies have been proposed for estimating centers of gravity in the scholarly literature, such as shown by Kandogan (2014) and Grether and Mathys (2010). The results and

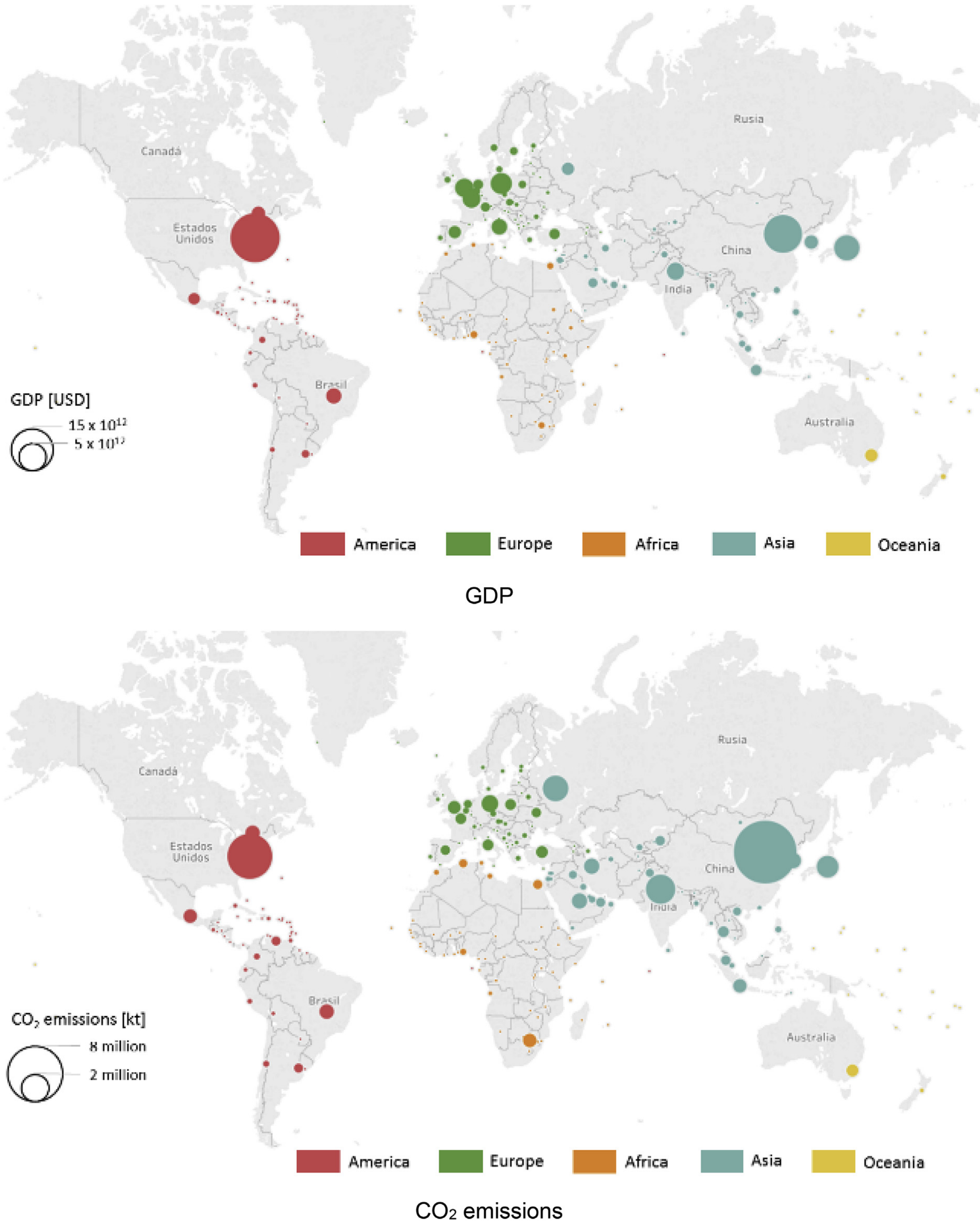


Fig. 1. Mapping for each indicator in the most recent year (2016, except for CO_2 emissions: 2014). Each node represents a country and it is located in the political capital. The size of the node corresponds to the value of each indicator in absolute terms (World Bank, 2016).

trends shown are quite similar, although they are differently represented due to the map projections. In this paper, we present a methodology for representing the center of gravity in the two-dimensional space, i.e., the so-called *flat gravity center*. For this, we employ the geo-processing software tool *ArcGIS* from *ESRI*. Our results are estimated and represented on a world map projected in *WGS84 World Mercator System*. This is a cylindrical projection with all the meridians run parallel to each other and they are equally spaced. The lines of latitude are also parallel but become farther apart toward the poles. Thus, all of the meridians and parallels

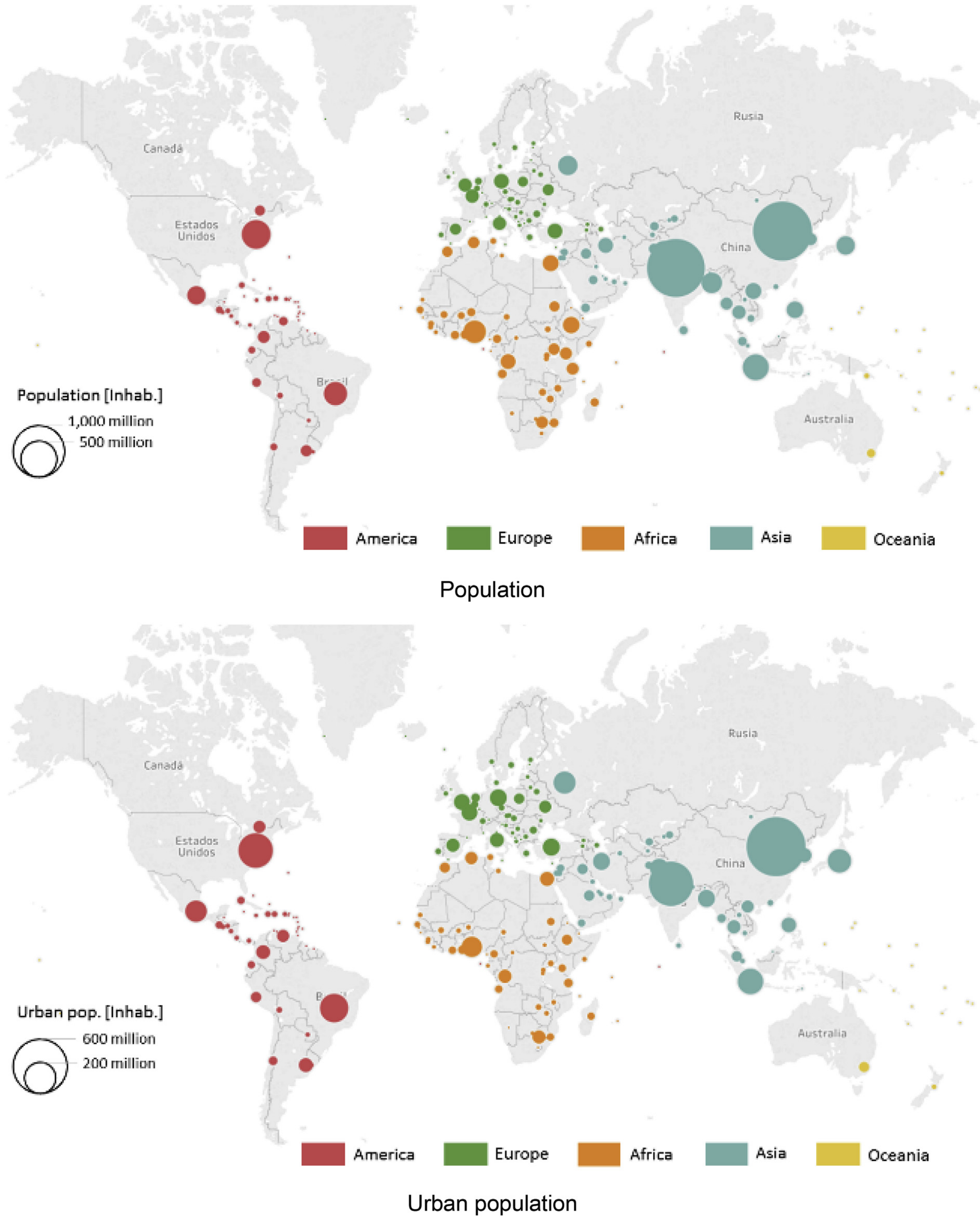


Fig. 1. (*continued*).

describe a regular grid. Among the properties, this projection's shape is conformal. Small shapes are well represented because this projection maintains the local angular relationships. Areas are increasingly distorted toward the polar regions.

3. Results

Fig. 1 shows that the United States, the European Union, China, and Japan are the largest economies as well as the largest emitters of CO_2 in the world. While population distribution is more concentrated in Asia (especially in China and India) and some African countries, the world's urban population is mainly concentrated in America, Europe, and the southeastern Asian countries where the largest cities and megalopolises are located. Fig. 2 relates GDP with the other indicators studied here. These charts show strong linear correlations, predicting that countries with higher

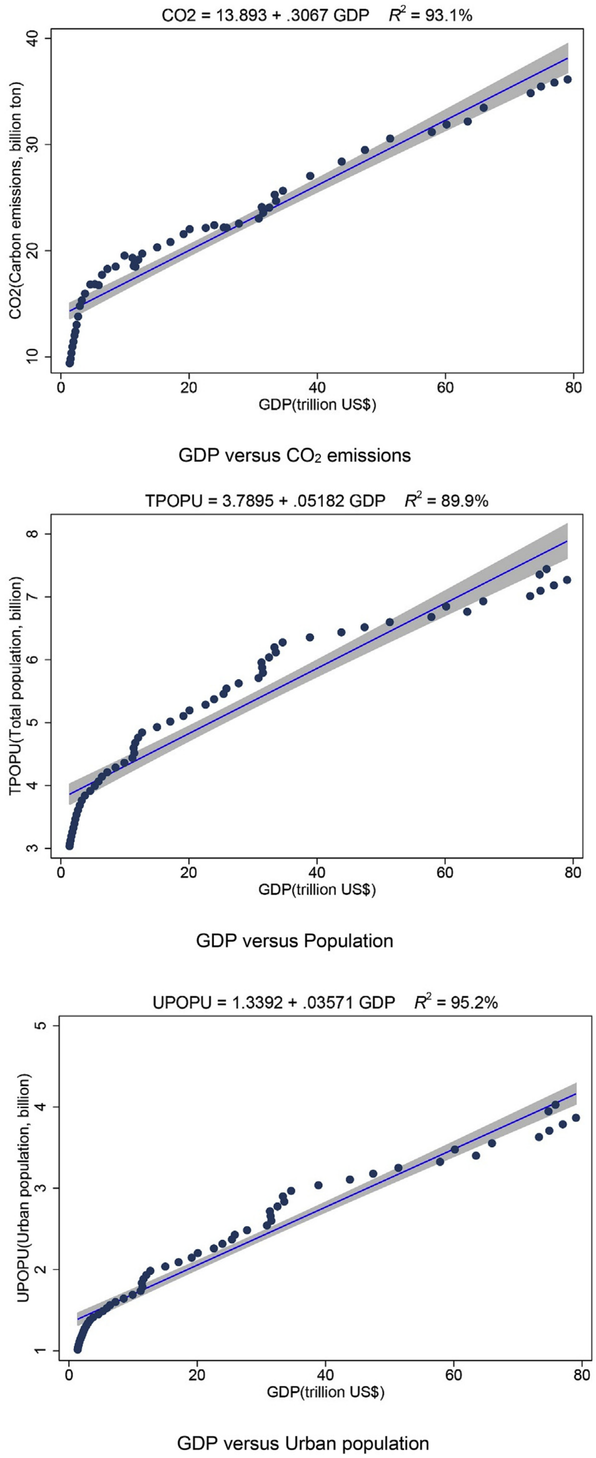


Fig. 2. Correlation between GDP and CO_2 emissions (R^2: 93.1%), population (R^2: 89.9%), and urban population (R^2: 95.2%) in the most recent year. Each dot corresponds to a country (World Bank, 2016).

GDP emit more CO_2 and they are more populated.

Based on these results, we estimate the location of the respective centers of gravity for each indicator and year. Resulting traces for the whole period are plotted onto a global map in Fig. 3. This map allows checking not only the relative position of gravity centers in the 2D space but also the trends drawn by the traces from the year 1960. GDP describes a trace with a west-to-east direction, although with certain intermediate fluctuations and interruptions. Its projection starts in the eastern part of the *Atlantic Ocean* between *Azores* and *Madeira*, ending in the middle of the *Mediterranean Sea*. A similar pattern is drawn by *CO_2 emissions*, whose trace runs approximately at similar latitudes. Its projection starts somewhere close to the GDP's center of gravity and continues with a west-to-east direction until a point near to the border between *Iraq* and *Iran*. The divergence between traces described by GDP and CO_2 emissions is more evident from the year 2000 when the trace described by CO_2 emissions is shifting east much faster than the one described by GDP. In fact, the Euclidean distance traveled by the GDP trace (4341 Km) is one-third less than the CO_2 emissions trace (6516 Km).

The *population* indicator describes a relatively short trace from southern *Iran* to *Qatar* with an east-to-southwest direction. Unlike the previous ones, distance traveled is much lower (633 Km in the Euclidean space), describing mostly a sinuous trend. Regarding the *urban population* indicator, it describes a sharp trace with a west-to-southeast direction. This trace starts from somewhere in the southeastern *Mediterranean Sea*, near to the northern coast of *Egypt* and it finishes in the center of *Saudi Arabia*. The Euclidean distance traveled by this indicator is 2041 Km.

The relationship between these traces is studied. For this, we analyze the correlation between the coordinates of each node with regard to the corresponding ones of the GDP's center of gravity in the same year. Here we represent the longitude and latitude of each gravity center by using the *X-* and *Y-coordinates* respectively. In Fig. 4, the *X-coordinates* of both CO_2 emissions and urban population are highly correlated with the GDP, with R^2 reaching 82.8% and 76.8% respectively. However, the *X-coordinate* of the total population is poorly related to the same one of GDP, with R^2 of just 21.5%. It indicates that the shift of the center of gravity of the total population in the X direction does not imply a shift of GDP in the same direction. In the other coordinate axis, the *Y-coordinates* of the total population and urban population are highly correlated with the *X-coordinate* of GDP,[1] with R^2 reaching 82.7% and 87.1% respectively. However, the *Y-coordinate* of CO_2 emissions is relatively weakly related to the X-coordinate of GDP with an R^2 of 41.3% (Fig. 4).

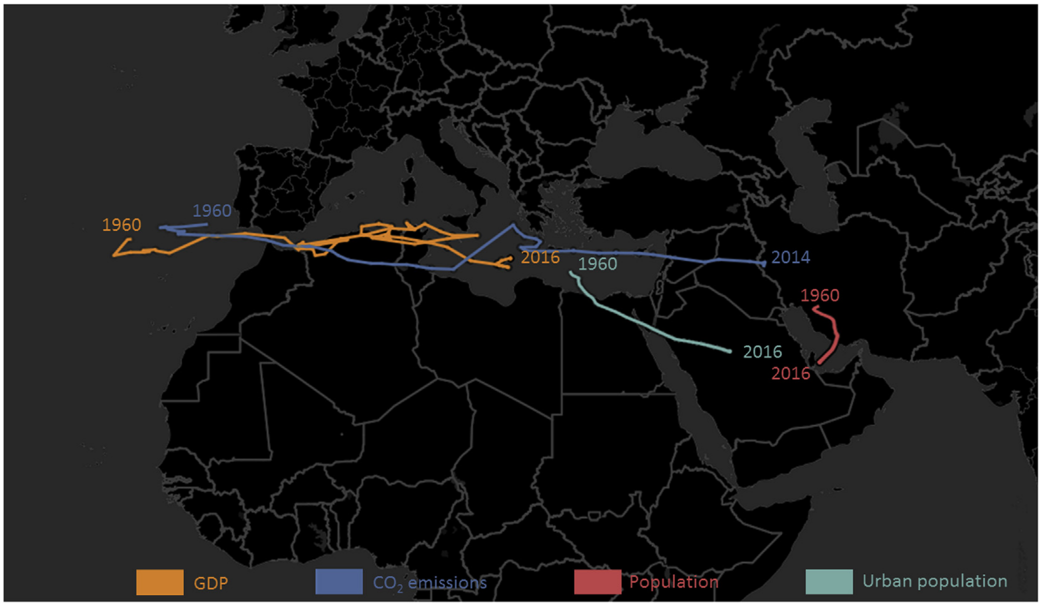
4. Data analysis and discussion

At this point, two important considerations should be taken into account. Firstly, we must analyze the data by countries/regions for understanding the location of the respective centers of gravity in each year. Secondly, the displacements over time of these centers of gravity must be understood in a relative manner due to the utmost relevance of some regions, but also to the downturn in others.

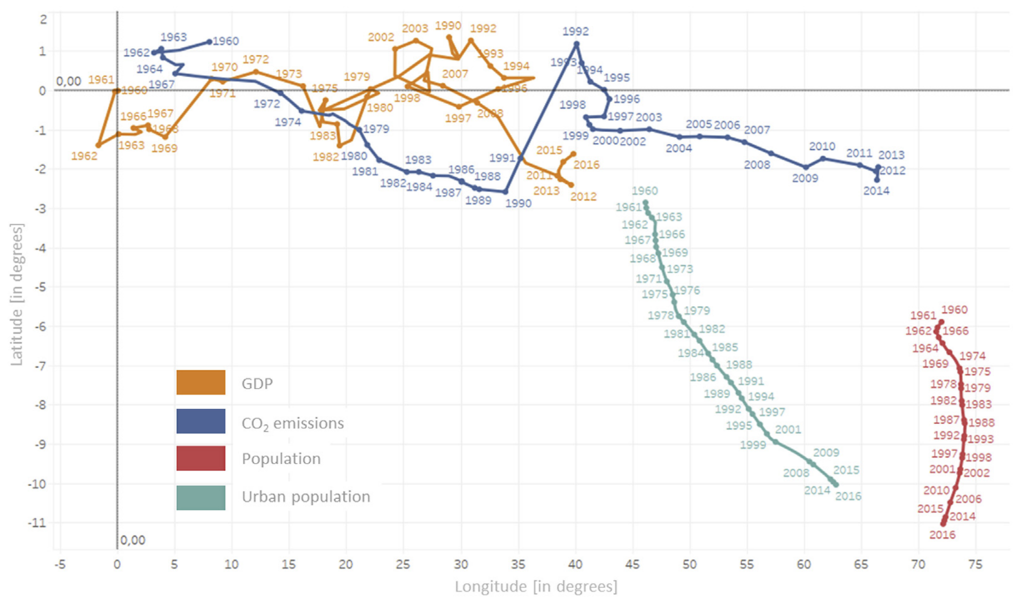
The northern hemisphere concentrates the most part of the world economy (Maddison, 2005). In fact, most of the global GDP is concentrated in a strip bounded by meridians 30 and 60 N, where the three main axes of the world economy are confined, i.e. (a) the United States, (b) the European Union, and the region of (c) *Eastern-Southern Asia*, including *Japan* (Fig. 5a). With regard to the global population, this distribution is not clear. The most populated Asian countries (*China* and *India*) clearly stand out from the rest, although some other countries in both hemispheres are relatively important (Fig. 5b).

It is possible to evaluate the capability and efficiency for

[1] We also estimated the correlation between the *Y-coordinate* of GDP with the *Y-coordinates* of the rest of indicators. The results showed a quite weak correlation with low relevance in the prediction model. For this, we only consider the *X-coordinate* of GDP.



(a)



(b)

Fig. 3. Traces described by each indicator. In (a) these traces are projected onto the global map. In (b), the coordinates for GDP in the year 1960 are considered the origin point of the reference system.

generating wealth at a country level by using two indicators: the GDP and CO_2 emissions. The location of global centers of gravity described by both indicators shows significant similarities. Thus, both centers of gravity are shifting from west to east and they are confined in a relatively narrow strip surrounding the *Mediterranean Sea*, between the meridians 33 and 38 N.

Since the 1990s, the global weight of the GDP of the United States has been reduced by a factor of 2.3 (from 56.9% of global GDP in 1960 down to 25% in 2016), while the Asian GDP has been increased by a factor of 2.4 (from 15.4% up to 36.7%). Asia had lived a hegemonic relay between *Japan* and *China* in the last decades. Japan lost more than half of its global weight (13.9% of global GDP in 1990; 6.6% in 2016), whereas China increased its global weight by almost 14 percentage points (1.6% of global GDP in 1990; 15.4% in 2016). The European Union, formed by 28 countries nowadays, represents a similar weight over the last decades, which corresponds to one-third of global GDP. These data show considerable discrepancies when they are associated with CO_2 emissions. The weight of the CO_2 emissions in the Asian region and China is, in relative terms, about twice the weight of its GDP (x 1.6 in the Asian region and x 2 in China). While the opposite occurs in Japan (x 0.5), the United States (x 0.6), and the European Union (x 0.3) (Table 1

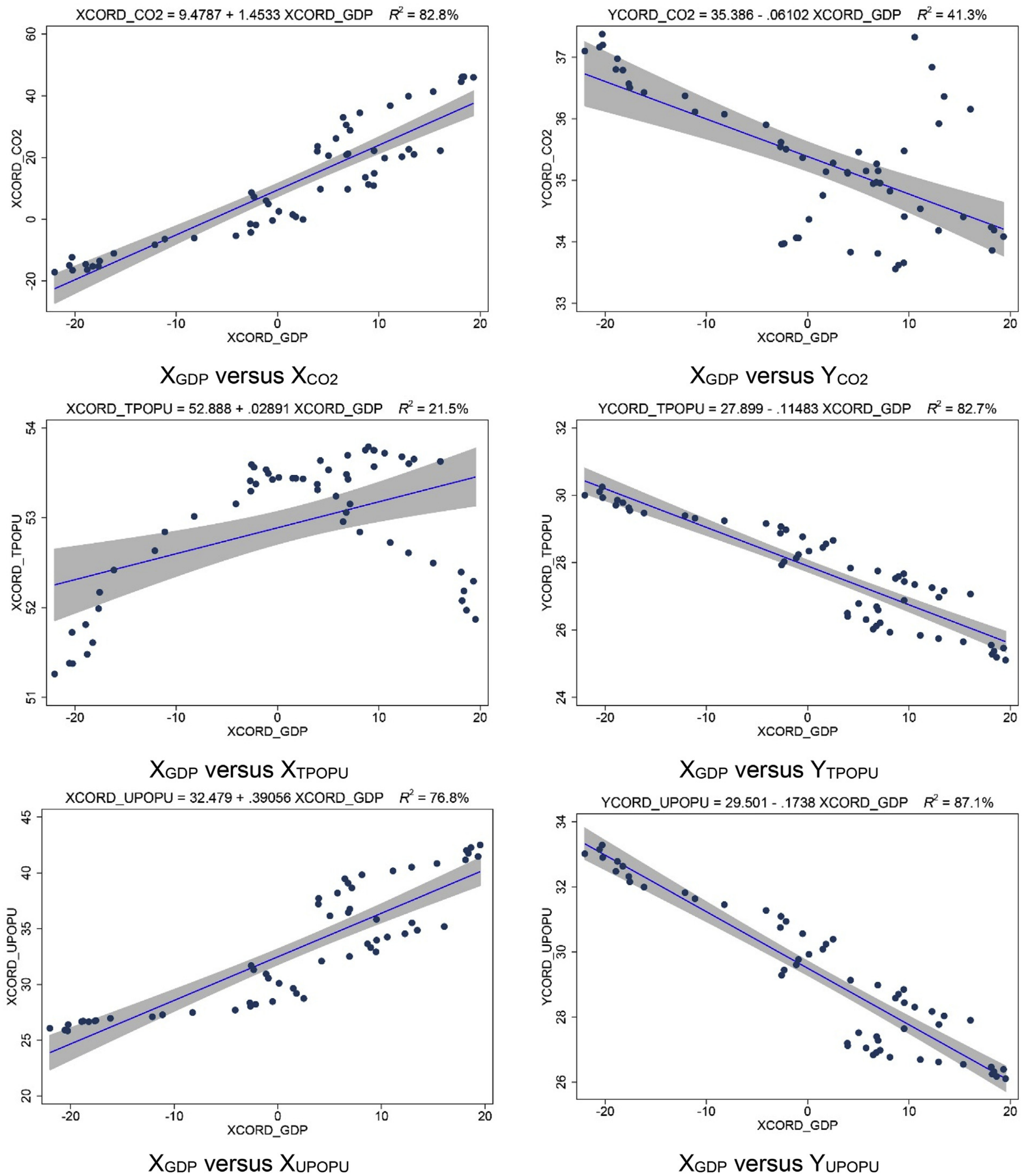


Fig. 4. Correlation between the *X-coordinates* (XCORD_GDP) corresponding to the GDP's center of gravity and the *XY-coordinates* of CO_2 emissions (XCORD_CO2, YCORD_CO2), total population (XCORD_TPOPU, YCORD_TPOPU), and urban population (XCORD_UPOPU, YCORD_UPOPU) during the period 1960–2016. Note that we use *X-coordinate* and *Y-coordinate* to represent the longitude and latitude of each gravity center respectively.

and Fig. 6).

At a global level, the west-to-east shift of the GDP and CO_2 traces may be explained by the minor relevance of the western countries, where wealth is traditionally accumulated, and the increasing influence of southeastern Asia. However, we must also emphasize that the trace of CO_2 emissions is located farther away to the east, which was also argued by Grether and Mathys (2009). This relates to the coupling/decoupling between the economy and energy at some point. The western countries have been at a stage of economic and industrial reconversion, focusing their economies on the services sector. In a global context, these countries have replanted their traditional industry in developing countries for reducing costs and for reducing ecological degradation. As a consequence, most of them have reached the so-called *strong decoupling* phase in which they are increasing GDP while reducing the ecological footprint in absolute terms (Szigeti et al., 2017).

Meanwhile, emerging countries with fast economic growth are at an early stage of industrialization. These countries increase their

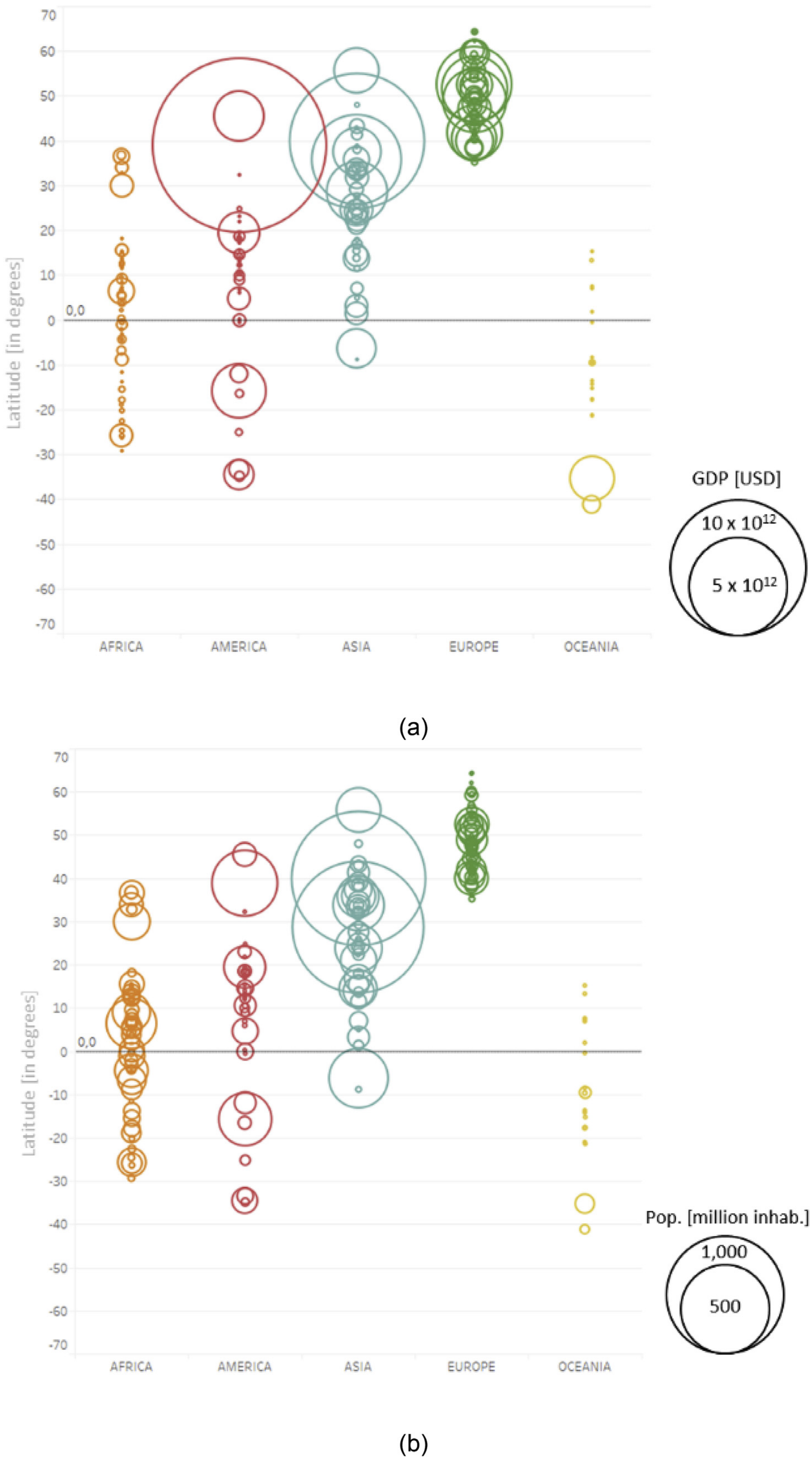


Fig. 5. Distribution of the (a) global GDP and (b) the world's population by countries and latitudes. The *X-axis* distributes the countries by continents. Each circle corresponds to a country, and each color refers to a continent. The *Y-axis* represents latitudes in degrees. The size of the circle plots the value of GDP and population by countries (World Bank, 2016). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Table 1
Relative weight of the main regions on a global scale. Some countries relatively significant today or in the past such as China and Japan are included.

	Gross Domestic Product		
	Year 1960	Year 1990	Year 2016
USA	56.9	26.6	25
EU	21.98	33.3	33.4
Asia	15.4	25.6	36.7
China	5.16	1.6	15.4
Japan	3.8	13.9	6.6

	CO_2 emissions		
	Year 1960	Year 1990	Year 2014
USA	43.6	30.2	15.5
EU	25.2	18.1	9.6
Asia	19.4	35.3	60.1
China	11.8	15.3	30.4
Japan	3.5	6.9	3.6

	Population		
	Year 1960	Year 1990	Year 2016
USA	6	4.7	4.4
EU	13.6	9.1	6.9
Asia	59.1	61.6	60.2
China	22.1	21.5	18.6
Japan	3.1	2.3	1.7

	Urban population		
	Year 1960	Year 1990	Year 2016
USA	12.5	8.3	6.6
EU	24.8	14.9	9.5
Asia	40.4	48	54.3
China	10.7	13.3	19.5
Japan	5.8	4.2	3

wealth in terms of GDP but showing an important inefficiency in terms of energy consumption. For this reason, the weak (or no) decoupling effect is observed in most of these countries. Some relevant studies analyze the economic growth in terms of ecological impact at different scales, assessing the pollutants and emissions generated (Wang et al., 2018), the level of energy inefficiency (Ang, 2006) or the consumption of natural resources (Leblois et al., 2017), among others.

This is happening in some countries of southeastern Asia, mainly China and India, in the last decades. These countries are living in an early stage of industrialization prior to the *economic maturity* that western countries are living right now. They experience a fast economic growth rate based on their high external competitiveness and the growing internal consumption. This internal market is potentially huge due to more than a third of the world's population is currently living in China and India. Their energy model is strongly based on fossil fuels such as coal, especially in China. This country produces 46.4% and consumes 50.1% of the coal in the world. While India produces 7.7% and consumes 10.2% (US Energy Information Administration, 2019). A comprehensive perspective of the energy market at a global scale is required to understand the model of economic growth in these countries and its future trends.

World consumption of oil is mainly located on three regions: United States (19.8 million barrels/day), European Union (15) and eastern Asia, led by China (13.2), India (4.6) and Japan (4). All these regions consume today 56.8 percent of the world's oil reserves (BP plc, 2018). With the exception of China and India, the rest of southeastern Asia is more dependent on oil. In fact, this region is the fastest-growing oil consumer in the world. However, this consumption per capita is very unbalanced within these regions. In fact, China consumed 9.5 barrels/day per 1000 inhabitants, and India 3.4 a decade ago. These data are much lower than in the United States (60.6 barrels/day per 1000 inhabitants), the European Union (29.3) and Japan (31.5) (Wu and Fesharaki, 2007).

The fast economic growth of some southeastern Asian countries is leading to an increasing dependence on oil imports from the Middle East. This is raising fears of potential conflicts. In fact, China consumes today around 6 times more oil than in 1990 (CEIC, 2017), being one of the countries with the most exponential growth in oil consumption in the last years. In contrast to the higher dependence on oil, this country is less dependent on natural gas, the source of fossil energy that will grow more in the coming years (International Energy Agency, 2018). The consumption of gas natural in Asia and the Pacific region is relatively modest. In fact, in 2005, this region produced more than 90% of the natural gas consumed (Wu and Fesharaki, 2007), although the consumption is exponentially growing in the last years.

China is living in a more advanced stage of industrialization than India, with a slight tendency to decoupling economic growth and emissions. This is largely due to a more rational consumption of electricity (Wang et al., 2019), the creation of strategic infrastructures (Liao et al., 2019), the implementation of eco-efficient policies in urban design (Juaidi et al., 2019), among other strategies. This new development phase, the so-called new *normal state*, presents a moderate growth while conducting structural optimization and energy conservation (Lin and Wang, 2019). While India lives now in an earlier phase of industrialization, showing a decoupling status relatively unsatisfactory (Wang et al., 2019). The traces drawn by GDP and CO_2 emissions at a global scale describe these trends, showing a pattern quite similar to what has happened in most of the time.

The traces related to population, both total and urban, show their own dynamics. The total population is roughly following a parallel line between 70 and 75° east and runs with a south direction. This trace is projected between somewhere in the south coast of Iran and runs towards the south, with direction to Qatar, being the trace drawn farthest to the east. This is due to the importance of the Asian population since the middle of the 20th century, which represent around 60% of the world's population. On the other hand, the European Union has lost almost half of its demographic weight in the world since 1960 (13.6% of world's population in 1960, 6.9% in 2016), while Africa has increased it by 1.7 (9.4% of the world's population in 1960; 16.4% in 2016) (Table 1 and Fig. 6).

The weight of the Asian population is nowadays similar to its global percentage of CO_2 emissions. However, it is much higher than the GDP that they generate. China is the exception to this statement. In fact, the Chinese population represents a similar percentage with its GDP, whereas its CO_2 emissions are considerably higher. In the case of the European Union, the United States and Japan, the importance of their respective populations are more

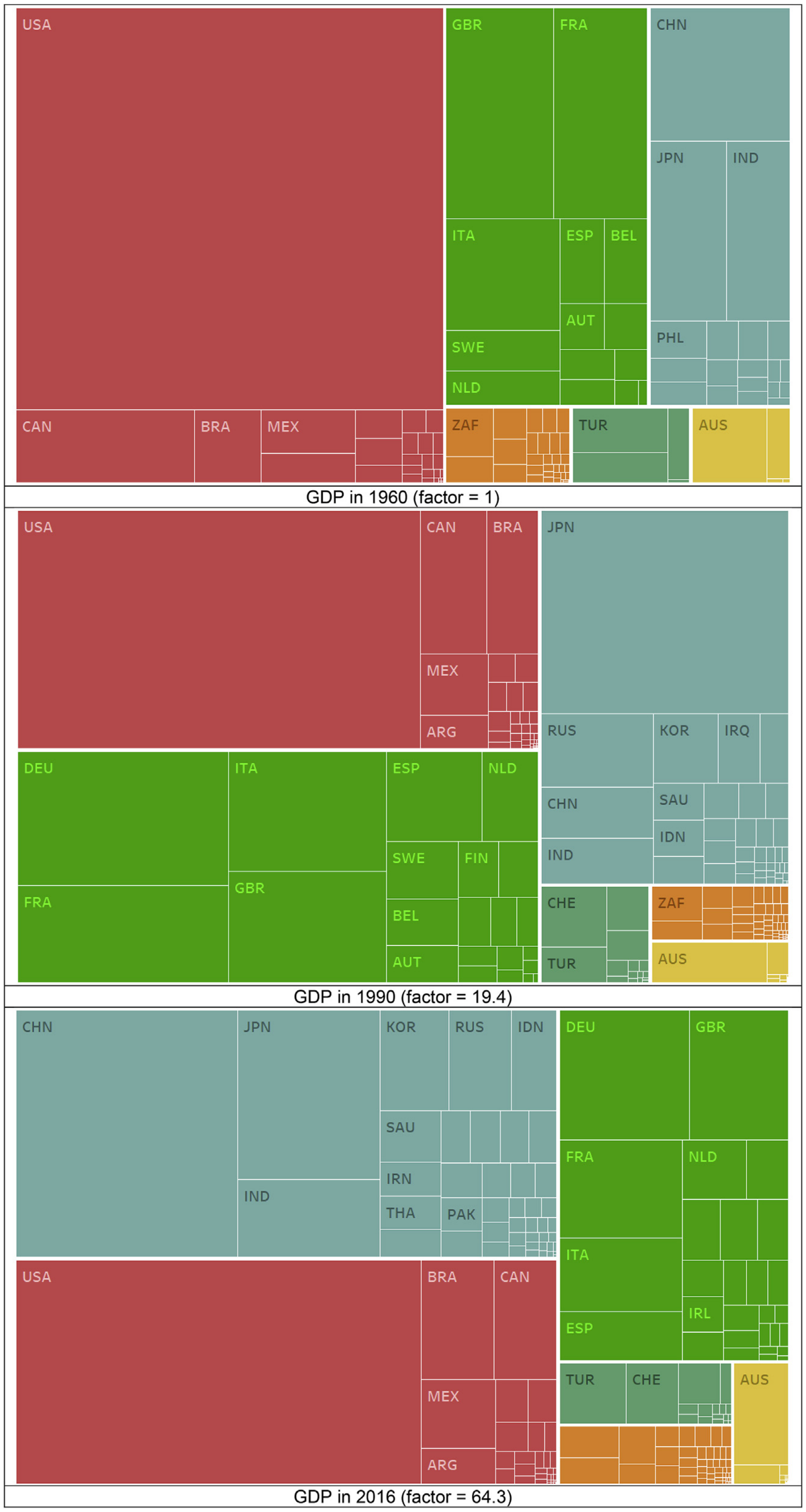
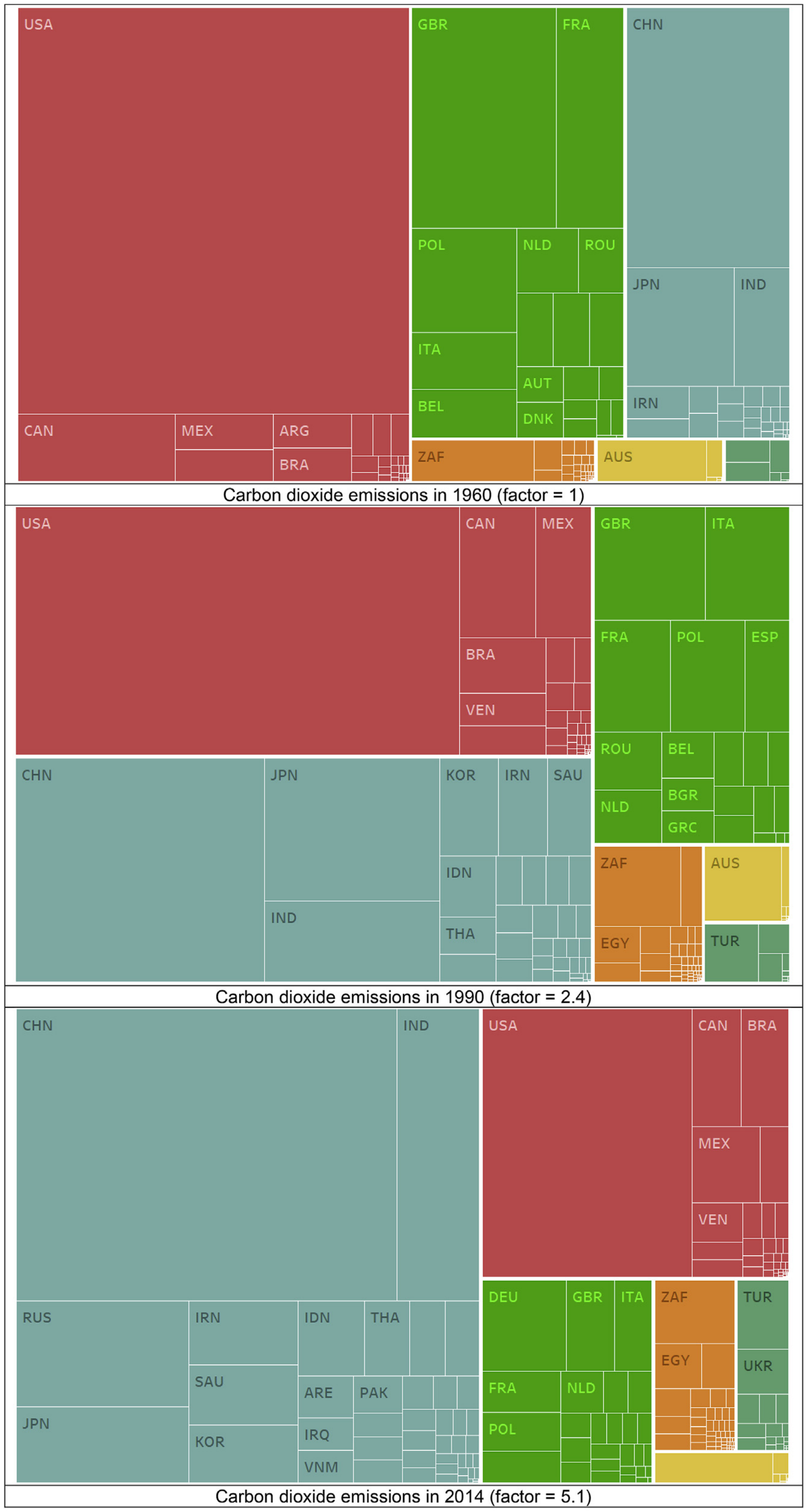


Fig. 6. Relative weight of the most relevant countries and regions on a global scale (See Appendix).

and more restricted over time (below 7%), but they still play a special role in the global economy. In fact, their GDP (and their level of CO_2 emissions) is gaining strength in relative terms, showing ratios of up to 6 times higher than their population's share. All these data reveal the existence of very significant inequalities, both internal and external, which may be observed at different scales.



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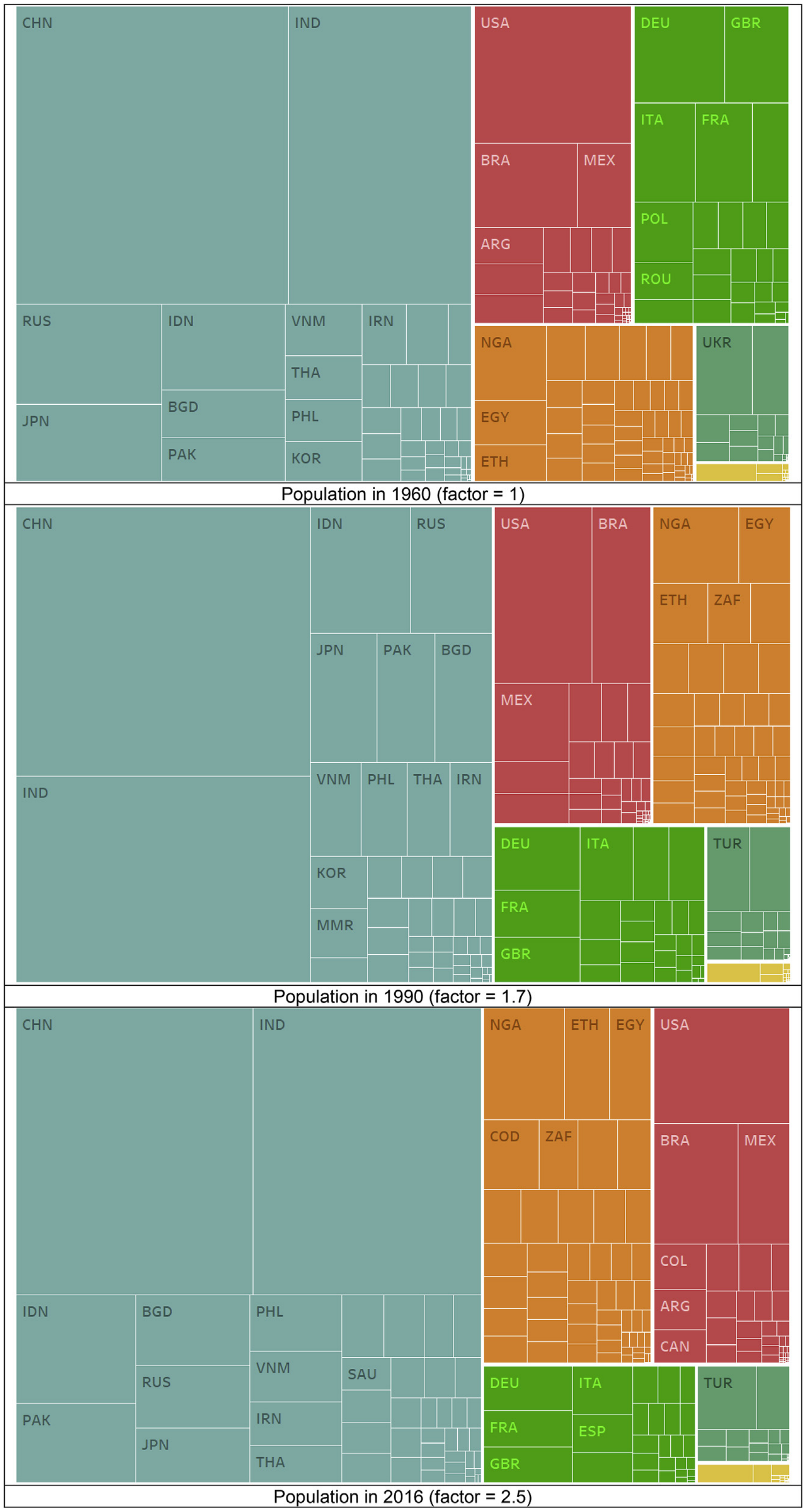

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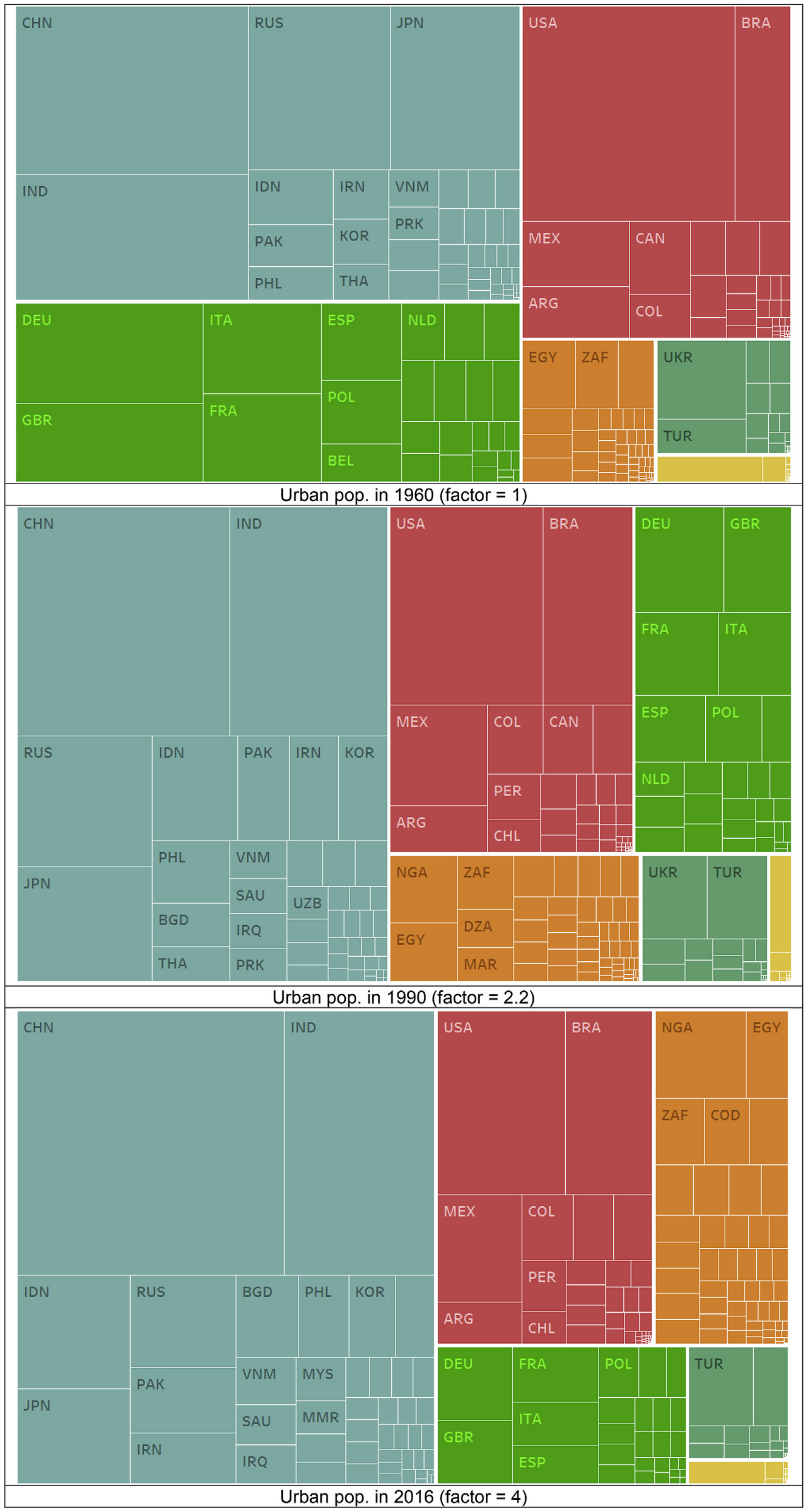

Fig. 6. (*continued*).

The urban population describes a trace slightly different from the total population. This is because of the degree of maturity of the urbanization process in each country (Bertaud and Malpezzi, 2003). The trace related to urban population is initially appearing much farther to the west than the others. This trace projects a route with direction to the southeast, from the most northwestern coast of Egypt reaching the central region of Saudi Arabia. Besides, this trace describes a much longer path compared with the trace described by the total population. This is probably due to the strong urbanization process that has taken place in some Asian cities, especially in China and India (Chauvin et al., 2017). With regard to Western countries, their cities show moderate levels of urban growth in the last years. At this point, the most significant trend that is expected deals with the urban explosion of Africa in the upcoming years.

This urban growth is not random at all. In fact, all the important economies in the world are urban economies (Frick and Rodríguez-Pose, 2018) and, for this, there is a natural trend to the natural growth of cities (Gill and Goh, 2010). The high levels of urban growth in China and India during the last decades are a consequence of strong economic growth. The urban population in China is nowadays 1.8 times higher than in 1960 (10.7% of the urban population of the world in 1960; 19.5% in 2016). Asian developing countries, especially China and India, now live in a transition stage with a large-scale urban shift. According to the *United Nations*, China's urban population could expand from around 555 million to 910 million between the years 2005 and 2025 (UNDESA, 2012). China's largest cities are increasingly concentrating most of its economic power. In 2010, more than 700 metropolitan areas in China with 200,000 or more inhabitants collectively accounted for 78% of the national GDP, which will be surely more in the coming years (Dobbs and Remes, 2012). On the other hand, India lives in a previous step in its transition towards an urban economy. In 2016, around 403 million of the Indian population (54.3%) lived in cities of all sizes, but it is expected that they will be around 590 million by 2030 (Sankhe et al., 2010). In the case of Africa, some countries are experiencing an important urbanization process, but it is hardly ever accompanied by any relevant process of industrialization. Nowadays, the urban population in Africa is 2.4 times higher than in 1960 (5.2% of world urban population in 1960; 12.4% in 2016), but this ratio will be surely much higher in the next years.

On the other hand, the urban population in Western countries is far less relevant on a global scale. Nowadays, the urban population in the United States and Japan is half the size they were in 1960 (United States: 12.5% in 1960 and 6.6% in 2016; Japan: 5.8% in 1960; 3% in 2016). Regarding the European Union, this relative loss is even more acute (from 24.8% in 1960 to 9.5% in 2016). Although Western countries had a more balanced urbanization process, the relative importance of their cities is lower in terms of both population and wealth at a national scale. In fact, around 55% of Europeans are living in large cities, accounting for less than 65% of GDP (Dobbs and Remes, 2012).

A review of the different centers of gravity confirms that human activities are more widespread around the world in the current economic context. Thus, economic development will happen in sequence, not in parallel, where some countries will experience rapid growth while others will become relegated (Venables, 2008). The traces are drawn by the global wealth -GDP and CO_2- are displacing in the direction of the meridians (heading eastward), while the demographic indicators -total and urban population-are moving in the direction of the parallels (heading south). This demonstrates that the fast economic growth and the early industrialization, and not the population *per se*, are the most important drivers of growth and environmental degradation in the last decades (Toth and Szigeti, 2016). Thus, while mature economies continue to maintain high levels of GDP concentration with demographic weights that are less relevant in a global context, it is obvious that flows of people from southern countries will tend to migrate to rich countries. This tendency is quite evident by reviewing the traces drawn by wealth and demographic indicators, which describe opposite directions.

The empirical findings introduced here prompt us to explore future trends of the centers of gravity represented. Thus, we estimate the center of gravity for GDP by using the economic projections of the *International Monetary Fund* at a country level during the period 2017–2023 (IMF, 2017). After that, we estimate the *XY* coordinates of the rest of the indicators (CO_2 emissions, total and urban population) from the *X-coordinates* of GDP. These estimations are based on the correlation models obtained for the previous years, which were shown in Fig. 4. The R^2 values obtained were above 80% for most cases. All the traces show similar trends for the next years (Fig. 7. Besides, some indicators such as the GDP and CO_2 emissions draw slight fluctuations toward the southeast. These may be explained by an economic slowdown in China or a higher relevance of India, both in absolute or relative terms.

5. Policy implications

Some policy implications may be extracted from this study to raise awareness about issues such as sustainable development, greenhouse warming, and climate change at a global scale. First, this study proposes a global focus on different indicators related to world development and some relevant human dynamics on a global scale. The interrelationship between these indicators offers a multifactorial study, where not only the economic growth (in terms of GDP and CO_2 emissions) is considered, but also the population (both urban and total population). In addition, we can understand much better how fast economic growth and early industrialization explain mostly the environmental degradation in the world (Toth and Szigeti, 2016). This study offers a comprehensive approach where the spatiotemporal dynamics associated with different

Figure 6: Relative weight for each indicator in the most relevant countries and regions with regard to the global world.

Most relevant acronyms of countries within each continent are:

Africa - Egypt (EGY), Nigeria (NGA) and South Africa (ZAF)
America - United States (USA), Canada (CAN), Brazil (BRA) and Mexico (MEX)
Asia - China (CHN), India (IND) and Japan (JPN)
Europe - [European Union] Germany (DEU), Great Britain (GBR), France (FRA), Italy (ITA), and Spain (ESP)
- [Rest of Europe] Turkey (TUR), Switzerland (CHE) and Ukraine (UKR)
Oceania - Australia (AUS)

Fig. 6. (*continued*).

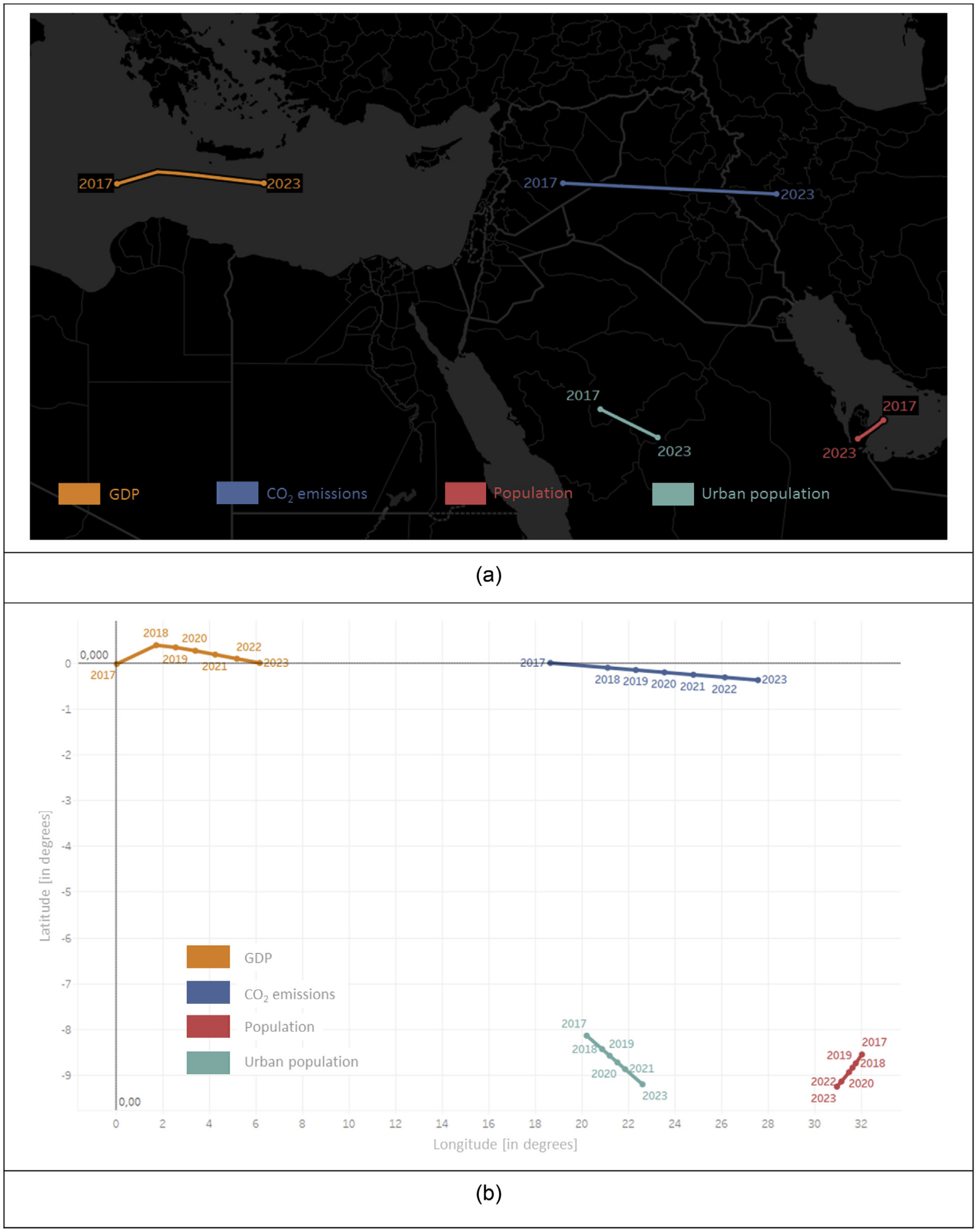

Fig. 7. Traces estimated based on the projections of economic growth of the *International Monetary Fund* for the period 2017–2023 (IMF, 2017). The XY coordinates for each indicator are relative to the XY coordinates for GDP in the year 2017, which corresponds to the origin point of the coordinate system.

development models have an impact worldwide. Therefore, all the strategies and policies that we will apply should consider the global effect.

Second, strategies for decoupling economic growth and energy consumption should be promoted in developing countries. Some recent studies argue that China is showing a slight decoupling, but not India. These insights can be interpreted in the results presented in this paper. In order to achieve sustainable development, developing countries must adopt policy measures to achieve the decoupling between economic growth and energy consumption, which is closely related to carbon emissions. These should consider the policies and strategies that are being implemented in China and India in order to determine their suitability in other countries. Thus, developing countries should promote the low-carbon transformation of their energy structure to reduce total energy consumption. Some specific measures must reduce the proportion of coal consumption and develop vigorously sources of renewable energy. These strategies should be reinforced for cities and urban areas because of the high concentration of people and the effects derived. Some experiences in this sense are being implemented through smart city policies in some Chinese cities in the last years (Yu and Zhang, 2019).

Third, territorial inequalities should be reduced at all different scales. Many studies have documented the unbalanced distributions of population (Li et al., 2019; Li and Liu, 2018) and firms (Li and Zhu, 2017) as well as their socioeconomic impacts at the intra-urban scale. In this study, we propose a more balanced model at a global scale in which the distances between production and consumption centers are minimized. This model allows to optimize costs related to transportation and to reduce emissions. To achieve this, territorial inequalities among regions must be reduced through the complementarity. For this reason, policies are highly important for promoting certain economic activities and industrial sectors in regions by considering both the demands of the population and the ecological impact. The major challenges will be in East Asia and Africa, where the rapid urban growth will imply a huge environmental impact, in addition to other important issues related with the emergence of strong social inequalities and territorial disparities.

6. Conclusions

Globalization is undergoing major changes in some relevant dynamics related to wealth, ecological impact and population. Understanding these changes is crucial to face these challenges. This paper shows how the global centers of gravity described by some relevant indicators related to economic growth and population provide relevant insights. Among them, the centers of gravity of GDP and CO_2 emissions are shifting towards the east, is more evident in the case of the second indicator. This demonstrates that the model of economic growth of some countries in Southeastern Asia requires high levels of consumption of resources. This was particularly true some years ago when China required great strength to develop. Nowadays China presents pieces of evidence of a certain *economic maturity*, showing more efficiency in the consumption of resources and energy. Meanwhile, India and other developing countries in Asia live in an early stage of industrialization, in which they will stay for the next years. The traces described by population, both total and urban, are shifting to the south. This is leading to an opposite reality in which the traces described by population and wealth are widening distant. This increasing confrontation evidences that migratory flows will become more frequent in the near future. This focused analysis is able to face some of the most important challenges on a global scale. The results predicted show the evolution and correlation between the different indicators.

Some limitations must be considered. Initially, we have assigned data related to whole countries to a single node that corresponds to the political capital of the respective countries. It might bear some incidence on the results, particularly in large countries with significant regional disparities. However, this is also true that it could make sense in a globalized world in which *mega-cities* are increasingly concentrating the economic weight of their respective countries (van der Ploeg and Poelhekke, 2008). Another limitation was the unavailability of data related to some countries during the first years. However, these were not particularly relevant in our results, because they were mostly small countries. Finally, the results shown in Fig. 3.a depends on the selected map projection. The third limitation is that we only focus on four basic indicators of global sustainable development. Future studies could incorporate more indicators related to sustainability such as poverty and innovation, some of which have been investigated at certain geographical scales (Li and Phelps, 2017, 2018)

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2019.117923.

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