resources

MDPI

Article

Spatial Evolution of the Energy and Economic Centers of Gravity

Géza Tóth and **Tekla Sebestyén Szép** *

Faculty of Economics, University of Miskolc, 3515 Miskolc-Egyetemváros, Hungary; Geza.Toth@ksh.hu
* Correspondence: regtekla@uni-miskolc.hu

Received: 11 April 2019; Accepted: 21 May 2019; Published: 24 May 2019

Abstract: Increasing energy demand and economic performance can be observed in emerging markets and, in parallel, their share in world energy use and in global GDP is growing as well. It causes significant spatial shifts and calls attention for a new geography of energy demand. The main purpose of this study is to reveal the spatial distribution of energy use and economic growth focusing on the link between them. Developing gravity models, we identify the economic and energy centres of gravity in the world and on different continents and reveal their movements between 1990 and 2015, in particular, the directions of the shifts. Bi-dimensional regression analysis and the method of standard distance are applied to compare these movements. The study utilizes cartograms to visualize how the space is changed and distorted by the field of force. It can be stated that the economic and energy centre of gravity can be found in the Mediterranean Basin, but a slow and gradual shift to the east can be observed. Currently it reflects the dominance of the north, but it marks the position loss of the northern hemisphere and the greater importance of developing economies (in the southern hemisphere).

Keywords: bi-dimensional regression; economic growth; energy consumption; gravity model; spatial models; structural change

1. Introduction

National and global energy consumption is influenced by many factors: e.g., the economic growth, population changes, urbanization processes, structural changes (alteration in the share of primary, secondary, and tertiary sectors), sectoral energy intensity, energy efficiency improvements, the energy mix and, finally, national energy policy.

1.1. Global Trends in Energy Use and Economic Growth—A Dynamic Shift

There are significant differences between developed nations and developing countries (emerging market and developing economies, see the description of the category in International Monetary Fund (IMF) [1]) regarding the energy intensity of their economy. As Figure 1 shows, while developed countries had produced more than four-fifths of the global gross domestic product (GDP) in 1990, this figure dropped below 65% by 2015. At the same time these nations have contributed to the world's energy use to a lesser extent (compared with other country groups): in 1990 half of the energy demand derived from developed countries, while in 2015 it was slightly more than 40% (according to BP [2] the energy use in non-OECD countries overtook Organisation for Economic Co-operation and Development (OECD) countries in 2008). Based on these ratios, many conclusions can be drawn: the economy of developed countries uses energy more efficiently, which can be explained by the development stage of the service sector, the applied technologies, and environmental and energy policies.

Modifications of these proportions cannot be considered as a final and closed process. According to the World Energy Council [3], scenarios report that primary energy demand during the period

2014–2060 is expected to grow at a slower rate (between 2014 and 2030 the growth rate will be probably 1.4–1.7%, while between 2030 and 2060 it is likely to range from 0.5–1%). However, the demand for energy, especially for crude oil and other fossil fuels, will stem from the emerging countries (not from the developed and industrialized nations), especially China and India. The modernization, industrialization, and urbanization processes contribute strongly to the growing and insatiable hunger for energy sources [4]. This tendency calls attention to the shift in economic and energy centres of gravity.

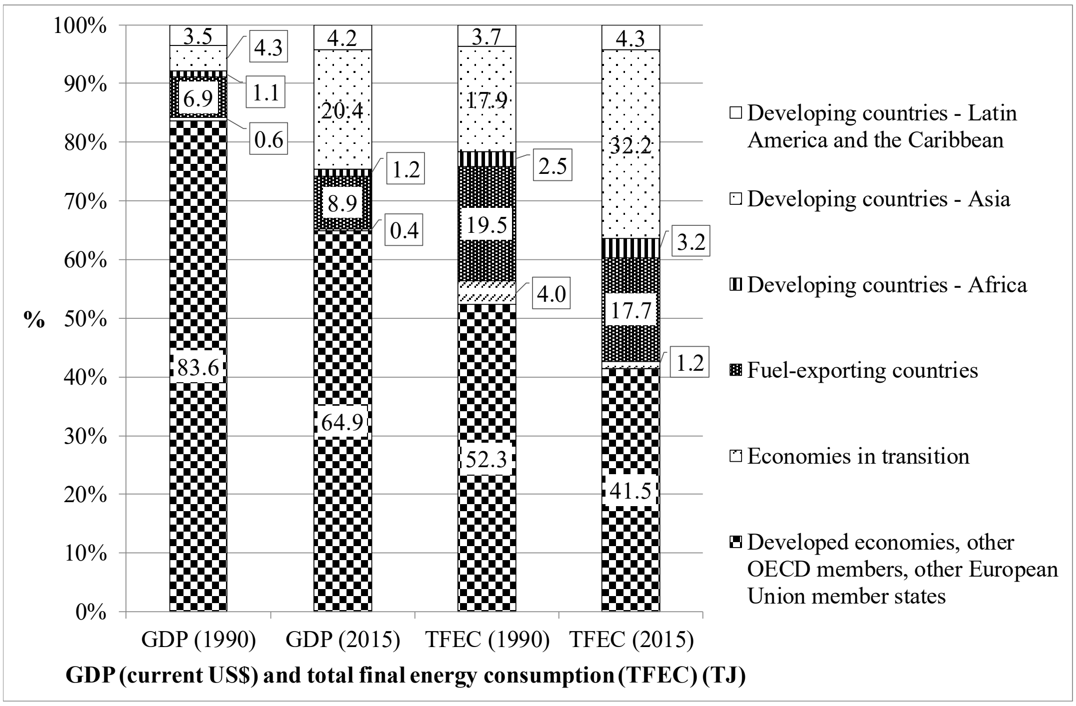

Figure 1. Share of global GDP and total final energy consumption (TFEC) among different country groups (1990, 2015, %). Source: own compilation based on World Bank databases [5,6].

In this study—as Table 1 shows—the energy consumption and economic growth are examined in five-year periods. In the group of developed countries a slight increase in energy use can be observed between 1990 and 2000 (it is 0.9% during the time period of 1990–1995 and 1.7% between 1995 and 2000 based on World Bank databases [5,6]). After that the growth stops; moreover, from the mid-2000s it shows a declining tendency. The causes of this are probably related to a number of events and trends: the economic and financial crisis of 2008–2010, economic development focusing on sustainability, structural change (outsourcing of energy-intensive industrial sub-sectors to developing countries), and energy efficiency measures (these countries take an active part in the climate change mitigation). However, the fuel-exporting and the developing countries show an intensive growth of energy consumption until 2010. As a consequence, the centre of gravity shifts from the northern hemisphere to the southern hemisphere. In our view the main reason for this is that, at the turn of the millennium, the world economy moved towards an unprecedented boom and global economic prosperity. After 2010 the total final energy consumption shows declining growth, and the main causes are in China. Looking at the Chinese economy the marks of possible overheating can be seen for years, meaning that the balancing mechanisms operate only poorly (increasing imbalances related to the Chinese yuan renminbi/US dollar (CNY/USD) exchange rate, the massive trade surplus with the United States of America (USA), decreasing savings, extremely high investment rate, and the danger of the shadow bank system). Although China's economy continues to grow, its rate of growth has steadily declined since 2010, which suits the main goals of the Chinese leadership [7]. Naturally this affects energy consumption as well. China is responsible for more than one fifth of the global energy demand (in 2017 it had become the world's largest net importer), so it has a significant role in not only the energy demand of developing countries but in influencing energy prices.

Table 1. Changes of GDP (current USD) and total final energy consumption (TFEC, [TJ]) in different country groups (%). Source: own calculation based on World Bank databases [5,6].

Title	1995/1990		2000/1995		2005/2000		2010/2005		2015/2010	
	Change in GDP (%)	Change in TFEC (%)	Change in GDP (%)	Change in TFEC (%)	Change in GDP (%)	Change in TFEC (%)	Change in GDP (%)	Change in TFEC (%)	Change in GDP (%)	Change in TFEC (%)
Developed economies, other OECD members, other European Union member countries	6.5	0.9	1.5	1.7	6.5	0.6	3.9	−0.2	1.0	−0.3
Economies in transition	−4.4	−10.5	−4.6	−3.1	21.0	1.7	12.4	−0.4	−1.6	−3.4
Fuel-exporting countries	−0.8	−2.0	2.3	0.5	14.5	2.3	17.0	3.2	1.6	1.6
Developing economies	10.4	3.4	3.3	1.1	9.8	5.7	17.9	5.0	7.8	3.3
from this:										
Africa	10.8	3.7	6.8	0.6	12.0	6.7	18.9	5.5	10.6	3.5
Asia	4.2	2.0	−0.1	2.1	12.3	3.3	10.0	2.4	1.6	2.8
Latin America and the Caribbean	12.7	2.7	−0.5	3.3	5.1	2.0	18.0	3.6	0.2	2.0
World	6.3	0.6	1.7	1.3	7.3	2.4	7.0	2.1	2.5	1.3

The economies in transition present an interesting group. In these countries of the former Soviet Union as a result of regime change and the radical structural change (relate to the decline of heavy industry) the energy use sharply declined until 2000 (related to the decline of heavy industry), and apart from a short time period it continuously decreases.

The visualization and map view of the processes described above are limited; just a few examples can be found in the literature focusing on centres of gravity (such as Zhang et al. [8] and Wang et al. [9]). Analysing the geographical differences in global energy use and in the world economy and explaining spatial processes are essential to realize and solve global problems. These provide information to the field of energy security, help tackle global environmental challenges, and contribute to carrying out deeper energy studies. Spatial modelling serves as a tool for examining the shift in the world's energy and economic centres of gravity and it helps to visualize this spatial evolution.

Our main research questions are the following. How did the energy and economic centres of gravity move during the period 1990–2015? Can there be a strong link between energy use and economic growth identified using the centre of gravity method and the model of two-dimensional regression? Is there significant difference between the global level and the level of continents?

1.2. Energy Consumption and Economic Growth

Opinions about the role of energy in economic growth range themselves along a very wide scale. Both the representatives of the ecological economics and energy economics argue that the main reason for economic growth is energy and energy use (as a production factor). Moreover, there is a radical viewpoint according to which energy consumption is the only indicator of development (such as the Olduva theory of Duncan [10]). This is explained by the important and unquestionable role of energy in the production process. Proponents of this stance argue that there is no economic activity for which there is no need for energy [11,12], based on the simple fact that production is a workflow and work needs energy investment [13].

Kovács [14,15] emphasizes in his research the strong relationship between energy consumption and economic growth; moreover, in his view "the economic welfare and well-being of a state is characterized by the level of energy use" [14] (p. 63), and "the mineral production and meeting the energy demand is one most important ways to enhance economic welfare and the standard of living" [15] (p. 47). Lakatos and Lakatosné Szabó [16] have a similar opinion and examine the connection between global GDP and oil demand.

Researchers from the field of ecological and energy economics tend to agree with the primary role of energy in economic growth. However, there is a significant difference in how they see this determinant role. Stern and Cleveland [11] emphasize energy availability, and according to Murphy and Hall [13] the increase in the amount of energy used is important. Berndt and Wood [17] and Schurr [18] were pioneers in recognizing the economic importance of energy quality: in their view the best available energy source at that time was electrical energy and furthermore—primarily—the improvements in energy quality contributed the most to the decreasing energy intensity. Stern [19] argues for the magnitude of energy quality in economic growth as well.

Ayres et al. [20,21] and Akizu et al. [22] explain the unprecedented economic growth during the first and second industrial revolution by the continuously declining real price of energy and with the increasing availability of energy. These changes "made human workers vastly more productive than they would otherwise have been" and most of the social classes gained access to energy (such as internal combustion engines) [21] (p. 185). In human history the first, second, and third industrial revolutions resulted in significant development, and it was "a result of a combination of the availability of a particular resource and the technological development of processing the available source" [22] (p. 18046). Most of the new technological improvements have been connected to previously unknown or not efficiently used energy sources (coal to the steam engine; crude oil to internal combustion engines; nuclear energy to cheap electrical energy).

A strong relationship can be observed not only between energy use and economic growth but between energy consumption and human development index (HDI) as well [23]. The basic assumption of the decoupling theory is also that there is a strong and causal relationship between these former two indicators. The term decoupling refers to breaking the link between the environmental pressure and economic driving forces (economic growth, GDP) and it looks at a possible way towards sustainable development.

This topic (spatial movements of global energy use, main causes of consumption, and reorganization of global energy markets) can be interpreted as the border of energy economics, energy geographics (Munkácsy [24] and Calvert [25] describe this in detail), and energy geopolitics (related to global economic growth and the increasing share of emerging nations). However, this study is closer to energy economics, because our main goal is to reveal the connection between economic growth and energy consumption and identify how these factors affect each other in space and time.

The analysis of the correlation and causal relationship between economic growth and energy consumption has been a central topic in energy economics for several decades. In this field of economic research the study of Kraft and Kraft [26] was the pioneering work, analysing the relationship between energy consumption and gross national product (GNP) in the USA between 1947 and 1974. In the more than four decades since then many publications have been issued but their results are often contradictory. These studies demonstrate the positive and strong correlation between the economic growth and energy consumption (e.g., [27–30]). However, it is not clear which factor is the dependent or independent one. According to Cleveland et al. [31] "the correlation between aggregate energy consumption and GDP in both industrialised and developing countries is undeniable. While industrial countries appear to have partly decoupled growth in energy consumption from growth in GDP in recent years, the close correlation reappears when energy consumption is weighted by the quality of different fuel types" (cited by Sorrell and Dimitropoulos [27] (p. 8)).

The starting point for our study is the assumption that there is a positive and strong correlation between energy use and economic growth in the world economy. That is why we find it expedient to examine the co-movement of these two indicators. Our hypotheses are as follows:

- The energy and economic centres of gravity move closely together not only globally, but also on a continental level.
- Conclusions can be drawn from the analysis of centres of gravity (from the gravity models) related to the causality directions of economic growth and energy use.

1.3. Fields of Force in the World, or the Centre of Gravity Method

Using methods based on gravity models is not new in the economic literature; Nagy [32] gives a comprehensive study on its application. Kincses and Tóth [33] found that the gravitational models based on physical analogy are used for spatial flow and to delimit catchment areas.

In the pioneering work of Quah [34]—which relies heavily on the experiences of Klein [35] and Grether and Mathys [36]—the dynamics of the global economy's centre of gravity are described between 1980 and 2007 based on 693 identifiable locations on Earth. He concluded that the world's economic centre of gravity is in the North Coast of Africa.

Based on the literature it can be stated that the research topic of energy centres of gravity is underrepresented; only a few papers can be found focusing on it (i.e., [8,9,37]). Fesharaki [37] first uses the term energy centre of gravity. In his analysis he argues that the centre of gravity of the world's energy market is shifting to the Asia-Pacific region, but his conclusion is mainly based on simple statistical analysis; no gravity model calculations were carried out.

The gap between Chinese energy supply and demand by energy sources (coal, oil, gas, electricity) is examined in Zhang et al. [8] using gravity models, for the time period of 1997–2009. The study reveals the spatial variations between energy production and consumption, making suggestions for infrastructure development.

The main purpose of Wang et al. [9] is to study the spatial distribution and centres of gravity for global energy supply and demand (oil, gas and coal) using the centre of gravity theory. Not only the movement of the centres of gravity is calculated, revealing movement towards the south-southeast, but the speed of this shift as well. However, we observe a lack of explanations and detection of main causes.

In the current study, we employ the gravity model to examine global and also continental energy and economic centres of gravity. In our view this study goes beyond the research objective of Quah [34], as our main goal is not to determine the economic centre of gravity and to follow its movements but to compare these spatial changes with the shift in energy centres of gravity. In this way the co-movements (convergence or divergence processes) become identifiable, which should serve to identify the relationship between energy use and economic growth and to analyse its spatiality. We strive to reveal the main causes and give comprehensive explanations of the shifts and their trends.

Our main goal is to identify the economic and energy centres of gravity in the world and on different continents and to reveal their movements, in particular the directions of the shifts. The rest of this paper is organized as follows: The Materials and Methods section introduces the centre of gravity method and bi-dimensional regression, and shows the database and the country classification system applied in the study. The results connecting to the shift in energy and economic centres of gravity are highlighted in maps and further conclusions are drawn based on two-dimensional regression, the Chow test, and the calculation of standard distance. Finally, the last chapter concludes this study.

2. Materials and Methods

Annual data for 204 data points (i.e., countries, territorial units, and provinces), as listed below, are applied in the calculations collected from World Bank databases [5,6]:

- GDP (current USD); and
- Total final energy consumption (in terajoule (TJ); abbreviated as TFEC).

The following country groups are made based on UN [38] and IMF [1] country classification methodology:

- developed economies are the advanced economies based on IMF [1], other OECD members, and other European Union member states;
- economies in transition based on IMF [1]: economies in transition in South-Eastern Europe and the Commonwealth of Independent States and Georgia (we note here that there is significant overlap between the category of economies in transition and the category of fuel-exporting countries; if a country is listed in the latter category, it is not listed in the former);
- fuel-exporting countries based on IMF [1] same category;
- developing countries: every other country located in Asia, in Latin America and the Caribbean, and in Africa; and
- The sample period is from 1990–2015.

2.1. The Gravity Model with Special Regard to the Centre of Gravity Method

Based on Nemes Nagy [39] the application of this model should be achieved as follows: "the co-ordinates of the gravity centres in a planar system consisting of n elements can be calculated as the weighted arithmetical means of the co-ordinates of the points in condition that the location of the points in the system of co-ordinates (map) is fixed and all the points are associated with 'weights'. The centre of gravity represents an optimal point: the weighted sum of the distances between gravity centre and the basic points is minimal" [39] (pp. 75–76). The equations are given as:

$$x = \frac{\sum_{i=1}^{n} f_i x_i}{\sum_{i=1}^{n} f_i} \tag{1}$$

$$y = \frac{\sum_{i=1}^{n} f_i y_i}{\sum_{i=1}^{n} f_i} \quad (2)$$

where x and y are the points of gravity (x, y); x_i and y_i are co-ordinates of basic points and f_i shows their weights.

The calculation can be carried out on any spatial unit, we can find examples for global analyses (such as Grether and Mathys [36] and Quah [34]) or regional analysis (such as Zhang et al. [8]). As Nemes Nagy [39] confirms, not only the population can be used as the role of weight, but any other social or economic variable (such as income, number of employees, energy use or emissions, etc.). Analysing the spatial transformation and the shift of the centre of gravity can reveal the distance and direction of changes in spatial structure. A disadvantage of the model is that "substantial changes in spatial structure can occur without a slight movement of the gravity centre, when the changes (growth or increase) take place symmetrically around the gravity centre" [39] (p. 76). Here we note that in this study global processes are examined. The complexity of world economic system and the diversity of the world's countries exclude the possibility of changes in energy use and economic growth taking place symmetrically around the gravity centre, which eliminates this problem.

Limitations of Gravity Model

Similar to an earlier study of ours [40] the geometric centre of the area for all countries is weighted by nominal GDP and TFEC obtained from the World Bank World Development Indicators and the Sustainable Energy 4 All databases. This method—especially for geographically large countries—raises many problems, because the geometric centre is far from any significant city or industrial centre. However, from our point of view, it is not the spatial location of the centres of gravity that is important but the changes over time and the co-movements of the two sets of points. Although the literature contains a method that eliminates the negative outcomes of the projection [41,42], we have chosen not to apply it. In our opinion, the original version of the centre of gravity method is best suited for the main objectives of this study. Naturally, the specific location of the centres of gravity is not considered relevant because the economic activity and the energy use are often confined to only a part of the country (such as China), while we weighted the geometrical centre of the entire national territory in this analysis. The examination of tendencies and spatial co-movements is much more important, as appropriate conclusions may be drawn from the results with respect to the direction of the processes taking place in the world economy.

The new information resulted by this method provides additional evidence for identifying world-wide processes and economic restructuring. ETRS89 (European Terrestrial Reference System) is applied to locate the points and create the maps, which is the current version of the standard spatial reference system operated by Eurostat. Our aim is to examine all the countries of the world's economic and energy centre of gravity together, while examining the continents (Africa, the Americas (North and Latin America), Asia, Australia together with Oceania, and Europe) separately. Here we note that in our model, Russia is considered as a part of Europe.

2.2. Application of Two-Dimensional Regression

The point set obtained by the gravitational calculation using GDP is worth comparing with the calculation using the total final energy consumption, examining how the space is changed and distorted by the field of force. The comparison, of course, can be done by a simple cartographic representation, but with such a large number of points, that does not really promise good results. It is much better to use a two-dimensional regression.

Two-dimensional regression is one the methods of comparing partial shapes. The comparison is possible only if one of the point coordinates in the coordinate systems differing from each other is transformed to another coordinate system by an appropriate rate of displacement, rotation, and scaling. Thus, it is possible to determine the degree of local and global similarities of shapes, as well as their differences, which are based on the unique and aggregated differences between the points of the shapes transformed into a common coordinate system. The method was developed by W. R. Tobler, who published a study describing this procedure in 1994 after the precedents of the 1960s and 1970s [43–47]. As for the equation relating to the calculation of the Euclidean version, see [48–50].

In Table 2 x and y are the coordinates of independent shapes; a and b are the coordinates of dependent shapes; a_i and b_i represent the coordinates of dependent shapes in the system of independent shapes; α_1 determines the measure of horizontal shift, while α_2 determines the measure of vertical shift; β_1 and β_2 are to derive the scale and angle values. Hence, α_1, α_2 represents a translation relative to the original location: up or down; and β_1 and β_2 indicates by how much the points have been rotated and expanded or contracted. Φ and Θ determine the angle of shifting. SST is the total square sum of difference, SSR is the square sum of difference explained by regression and SSE is the square sum of difference not explained by the regression (residual). Further details about the background of the two-dimensional regression can be seen in [50] (pp. 14–15).

Table 2. The equations of the bi-dimensional Euclidean regression. Source: [47,49] as cited by [50] (p. 14).

Step	Equation
1. Equation of the regression	$\begin{pmatrix} A\prime \\ B\prime \end{pmatrix} = \begin{pmatrix} \alpha_1 \\ \alpha_2 \end{pmatrix} + \begin{pmatrix} \beta_1 & -\beta_2 \\ \beta_2 & \beta_1 \end{pmatrix} * \begin{pmatrix} X \\ Y \end{pmatrix}$
2. Scale difference	$\Phi = \sqrt{\beta_1^2 + \beta_2^2}$
3. Rotation	$\Theta = \tan^{-1}\left(\frac{\beta_2}{\beta_1}\right)$
4.Calculation of β1	$\beta_1 = \frac{\sum(a_i-\bar{a})*(x_i-\bar{x})+\sum(b_i-\bar{b})*(y_i-\bar{y})}{\sum(x_i-\bar{x})^2+\sum(y_i-\bar{y})^2}$
5.Calculation of β2	$\beta_2 = \frac{\sum(b_i-\bar{b})*(x_i-\bar{x})-\sum(a_i-\bar{a})*(y_i-\bar{y})}{\sum(x_i-\bar{x})^2+\sum(y-\bar{y})^2}$
6. Horizontal shift	$\alpha_1 = \bar{a} - \beta_1 * \bar{x} + \beta_2 * \bar{y}$
7. Vertical shift	$\alpha_2 = \bar{b} - \beta_2 * \bar{x} - \beta_1 * \bar{y}$
8. Correlation based on error terms	$r = \sqrt{1 - \frac{\sum\left[(a_i-a_i')^2+(b_i-b_i')^2\right]}{\sum\left[(a_i-\bar{a})^2+(b_i-\bar{b})^2\right]}}$
9. Breakdown of the square sum of the difference	$\sum\left[(a_i-\bar{a})^2+(b_i-\bar{b})^2\right] = \sum\left[(a_i'-\bar{a})^2+(b_i'-\bar{b})^2\right] + \sum\left[(a_i-a_i')^2+(b_i-b_i')^2\right]$ SST = SSR + SSE
10. Calculation of A′	$A\prime = \alpha_1 + \beta_1(X) - \beta_2(Y)$
11. Calculation of B′	$B\prime = \alpha_2 + \beta_2(X) + \beta_1(Y)$

2.3. Examination of Shift in Centres of Gravity (Standard Distance)

To describe the movement of centres of gravity, the standard of distance is measured. It is an indicator for spatial deviation of points. It measures the degree to which features are concentrated or dispersed around the gravity centre (in an input feature class) [51]. The larger the value, the less characteristic it is that the given social or economic variable concentrates around the gravity centre [39]. The first step in measuring the standard distance is to calculate the mean centre of the centre of gravity, which is actually the average mean of the coordinates of the centre of gravity. The average movement of coordinates is compared with the mean both in the whole time period and in its two phases, as well. Basically the standard distance is the average and weighted distance of centres of gravity; it is the radius of a circle drawn around an average centre. The formula of standard distance is:

$$S_D = \sqrt{\sum_{i=1}^{n} \frac{(X_i - \bar{X})^2}{n} + \sum_{i=1}^{n} \frac{(Y_i - \bar{Y})^2}{n}} \quad (3)$$

where S_D is the standard distance (in this case geographical coordinates), X_i and Y_i are coordinates of gravity centres, $\bar{X}$ and $\bar{Y}$ are the coordinates of the average centres and n is the number of years.

2.4. Chow Test for Structural Changes

In a situation when a significant shift occurs in the direction of a centre of gravity, we obtain a structural break. This can be tested with the Chow test. Actually the Chow test contributes to verifying whether one or two separate regression lines best fit a split set of data. To do that, the time series data are divided into two subsamples (A and B) based on a date. For calculating the Chow F statistic the formula is [52] (p. 334):

$$F_c = \frac{(RSS_R - RSS_1 - RSS_2)/k}{(RSS_1 + RSS_2)/(n - 2k)} \quad (4)$$

where RSS_R is the residual sum of squares of the model using the entire pooled sample, RSS_1 is the residual sum of squares of the model using only subsample A, RSS_2 is the residual sum of squares of the model using only subsample B. A and B are two distinct subsamples. The null hypothesis for the test is that there is no break point. Under H_0, the F-statistic follows an F-distribution with k and $n - 2k$ degrees of freedom (k is the total number of parameters).

3. Results

Before presenting our calculation results and the spatial evolution of the energy and economic centres of gravity, we highlight the changes in the position of world nations regarding changes in the total final energy consumption and GDP between 1990 and 2015 based on World Bank databases [5,6]. It reveals the energy and economic trends in a structured way. In the visualization process the formerly-presented country classifications were followed. The four corners of Figure 2 show four types of development pathway. In the countries, located in the upper left corner of the Figure 2, while the average annual growth rate of total final energy consumption is above the world average, the economic growth rate does not follow it (it was under world average). In the bottom right corner, the trends are the opposite of that. In the upper right corner, the average annual growth rate of both indicators is above the world average, in the bottom left corner it is below average.

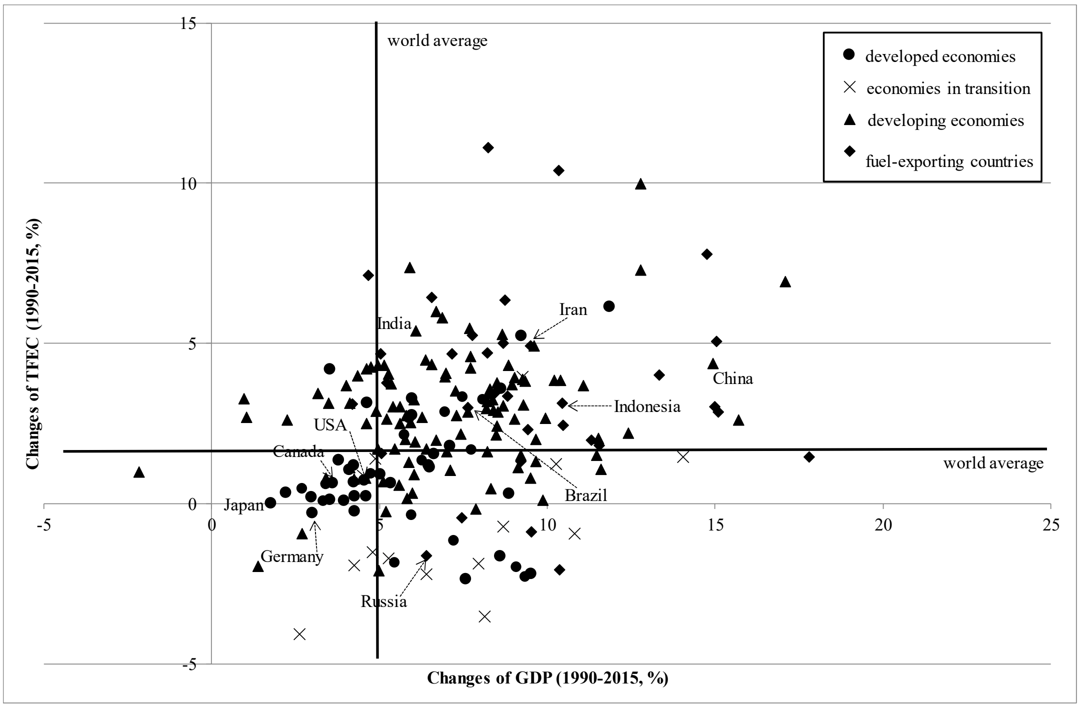

Figure 2. Changes in the position of world nations regarding changes in total final energy consumption and GDP (1990–2015, average annual growth rate, %). Source: own compilation based on World Bank databases [4,5].

Furthermore, Figure 2 gives additional information. It specifies the top 10 energy consumer countries based on their share of global final energy consumption [6]. In this list there are four developed countries (in order of energy use the rank is: the USA, Japan, Germany, and Canada) and these nations can be found in the bottom left corner. This placement means that the average annual growth rate of GDP and TFEC are under the world average. This can be explained by the significant share of the tertiary sector (which is much less energy intensive), energy efficiency improvements, stagnation of population numbers (Japan, Germany) and small but balanced growth (Canada, the USA). These countries have already performed absolute or relative decoupling, so they could succeed in breaking the link between environmental pressure and economic driving forces (for more details see Szlávik and Sebestyén Szép [53]).

Considering the group of transition economies, only Russia (located in the bottom right corner of Figure 2) belongs to this top 10 list. While the average annual growth rate of its TFEC is below the world average, its GDP is above average. In Russia the negative consequences of the decline of heavy industry, the deindustrialization and restructuring, can still be felt. According to the World Bank databases [4,5] and Weiner [54] the Russian economy managed to reach the production level of 1991 (the year of the dissolution of the Soviet Union) only in 2006.

In the upper right corner of Figure 2 (where the average annual growth rate of both indicators is above average) are located China, India, Brazil, Indonesia, and Iran. The last two belong to the group of fuel-exporting countries (we note here that, in Indonesia, the export of fuel exceeds import by a few percentage points), and Iran was the 10th largest net exporter in 2015 as a result of the lifted sanctions (connected to the Iran nuclear deal). However, some duality characterizes Iran. The energy efficiency of its economy (calculated as units of GDP per unit of energy) based on World Bank databases [5,6] is far from the world average. In 2014 it was 5.6 USD (2011, purchasing power parity (PPP)), while the global average at that time was 7.9 USD. However, at 3023.5 *kilogram* of *oil equivalent* (koe) the energy use per capita is extremely high (the world average is 1919.4 koe), the same as in the European Union. The main reasons are in connection with the high share of energy-intensive industrial subsectors (oil production and refining) in the economy, the less-developed transport sector (road transport dominancy), and the substantial subsidizing of energy prices (in the latter case the government recently embarked on an aggressive energy price reform—see Moshiri [55] for more details). As for China, India and Brazil, they clearly appear in the top 10 as a result of their expansive economic policies, increasing population and the industrialization process, producing these high rankings as the largest energy consumers in the world.

Hereinafter the shift in energy and economic centres of gravity are presented (Figures 3 and 4). In Africa both these centres of gravity nearly overlap with the geometric centre of the continent, located in the Central African Republic and in the Democratic Republic of the Congo. The shifts are small, but in many cases these move hectically: while the energy centre of gravity clearly moved towards the north (primarily as a result of rapid population and economic growth in North Africa), the economic centre of gravity followed that route until 2001/2002, after which it turned to the south until 2010, from which it moved again towards the north.

Probably the continent of the Americas shows the clearest picture about the vulnerability of developing countries lacking export diversification. These nations gained extra benefit from export-led growth, but, in parallel, the exposure of such economies to economic crisis and price volatility of raw materials is very high. As a result of reform processes after the debt crisis in 1980s, South America showed intensive economic growth in the first half of the 1990s. During this time period (1990–1995) the economic centre of gravity moves towards the southeast. However, the 1997–1998 Asian financial crisis strongly influenced their economies and this led to steps backwards in the development that had only just begun. As a consequence, the centre of gravity shifts towards the northwest again.

In the early 2000s the bursting of the dot-com bubble resulted in an economic slowdown in North America, but the economic performance of Argentina and Brazil developed, and as a consequence the economic centre of gravity shifted again towards the southeast. For a long time, it seemed that the 2008–2009 financial crisis would avoid South America, but, finally, the negative effects of the price decline of raw materials (and later its stagnation) and the declining growth of the world economy (especially in China) reached the continent. The investors lost their appetite for emerging (and developing) markets, so these negative tendencies turned the shift of centre of gravity towards the northwest.

By contrast the energy centre of gravity moved clearly towards the southeast during the examined time period and it is not influenced by the various economic crises, either. One factor is in connection with improvements in energy efficiency in North America, while another is the decrease in the TFEC due to the development of the service sector and structural changes. As North America becomes more and more efficient, the energy use per capita is shrinking (between 1990 and 2015 it reduced by more than 10%) and the energy intensity improves (less energy is required to generate one unit of GDP). Energy intensity increases by 55% during the examined time period in the USA, based on World Bank databases [4,5]. In contrast, in the global South the energy use per capita continuously increases thanks to the rising standard of living and economic development, while the energy intensity of the economy does not significantly change.

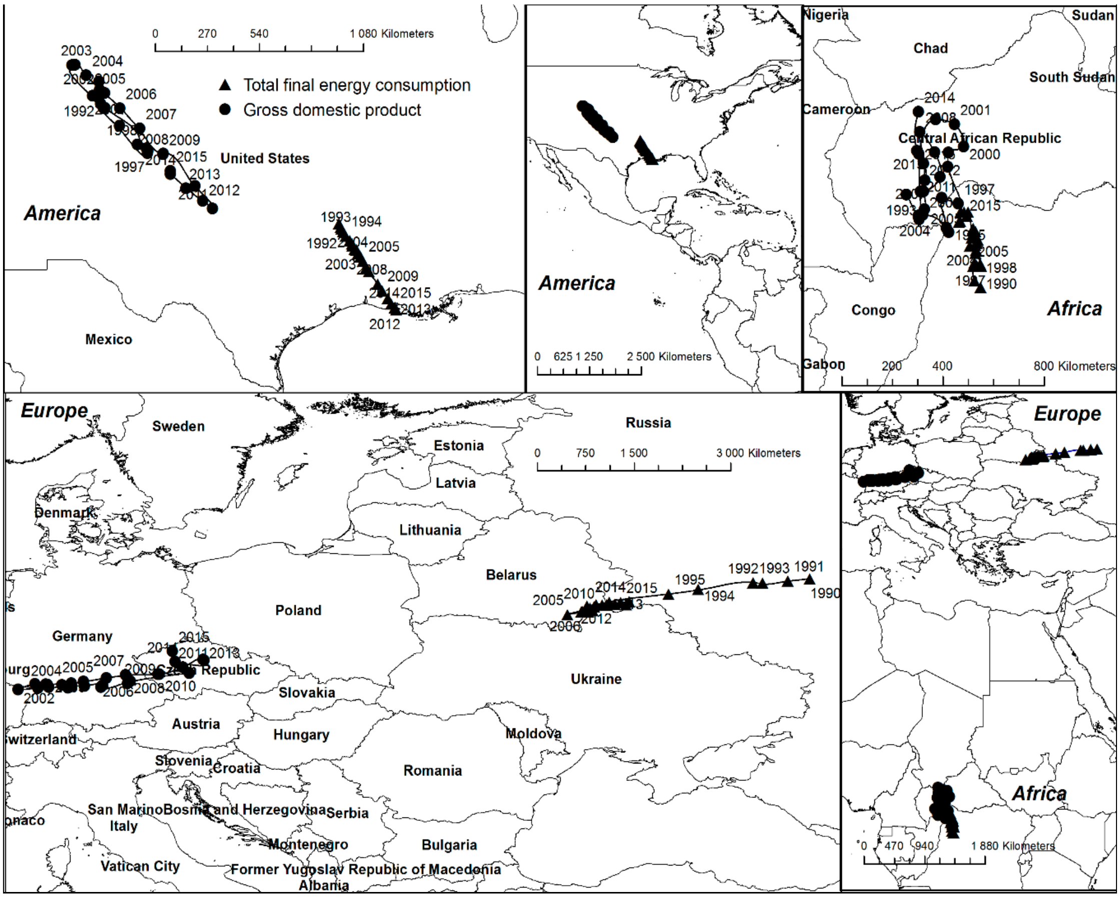

Figure 3. Shift in economic and energy centres of gravity for the continents of Africa, Europe, and the Americas (1990–2015). Source: own compilation.

In the case of Europe, remember that Russia is considered as a part of Europe in this study. Our decision to include it is primarily justified by the fact that that most of the Russian economic performance and population is tied to Europe, geographically. In this study we ignore the geopolitical theories according to which Europe is only the western peninsula of the giant "supercontinent" of Eurasia and that find Eurasia (as a political force field) to be one of the most important geopolitical concepts (see Brzezinski [56]). The geometric centre of Russia is located in the eastern part of Russia. Figure 3 highlights that Europe is the only continent where the economic and energy centres of gravity move together, but a five-year delay can be observed. The direction of the shift was west-southwest, but while the economic centre had turned to the east with the economic growth in 2000, in the case of TFEC this change happened later (only in 2005). This can be related to the fact that after the regime change in East-Central Europe the industrial output sharply declined (over a few years) but as a result of the economic liberalism and the fast adoption of privatization policies, the volume of inward FDI flows increased, contributing to significant economic growth. The banking system started to develop and the share of the tertiary sector increased. The region gradually regained its economic position in the continent. After 2005 the energy use tendency stopped falling, and stagnation of energy intensity could be observed. The re-industrialization process became more significant after the 2008–2009 financial crisis and the national share of the industrial sector increased again. As a consequence, the energy centre of gravity shifted again towards the east.

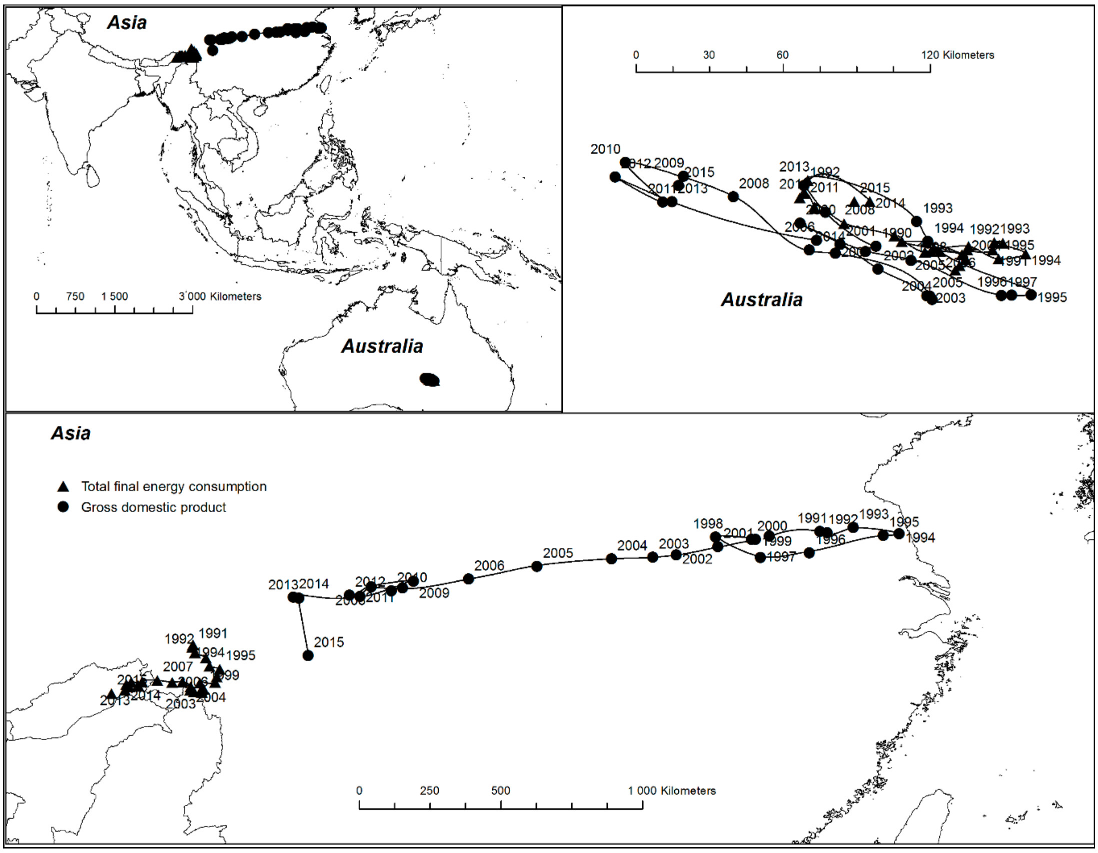

Figure 4. Shift in economic and energy centres of gravity in the continent of Asia and of Australia together with Oceania (1990–2015). Source: own compilation.

In Asia the economic centre of gravity was located in China between 1990 and 2015; however, the energy centre of gravity moved to the eastern part of Bangladesh after 2007. Until 1995 the economic centre of gravity moved towards the east as a result of the increasing economic performance of the Tiger Cub Economies. After that, with its successful reform and opening-up policy, China became an increasingly important player on this continent. In parallel with that, after the turn of the millennium the economic centre of gravity shifted west. From 2014–2015 a sharp movement can be observed towards the south-southeast, caused by declining Chinese economic growth.

The movement of the energy centre of gravity is less dynamic in Asia than the economic centre. Up to 2000 it moves towards the southeast, after that clearly towards the west—this is in connection with the growing energy hunger of India. According to IEA [57], in 2016 India was the 2nd largest net coal importer (after China) and 3rd largest net oil importer in the world. However, probably this shift is smaller—compared with the GDP—because the structural change of the economy on the continent is delayed; though the share of the industry is still significant, serious restructuring cannot be observed.

In the case of Australia and Oceania the economic and energy centres of gravity move within Australia. The size of the shift is not significant; Australia dominates the geographical region.

We conclude that globally the examined time period can be divided into three main parts (Figure 5). Between 1990 and 1995 the shift of the energy and economy centres of gravity passes in the opposite direction. The economic centre of gravity moves to the southeast, indicating the rise of China and the success of the Chinese economic reform (for more details see Simon [58]). In spite of that, the energy centre of gravity moves towards the south-southwest direction. This can be explained by the dramatic structural change, with special regard to the decline in the industrial output and to the post-Soviet heavy industrial meltdown, which was one of the most significant energy-intensive industrial sectors earlier. From 1995–2000 no significant shift can be identified; this time period can be labelled as path searching. One year the centre of gravity moves towards one direction, the next year towards the opposite direction. This tendency is caused by the fact that after collapse of the Soviet Union in 1991 the world became unipolar, but it was a very short-lived situation; new challengers appeared (emerging markets) on the world stage. Naturally, these processes pull the centres of gravity in different directions. Around 2001–2002 a kind of uncertainty ceased, and both the energy and the economic centres of gravity moved to the east-southeast. After 2001–2002 both centres of gravity moved together; the size and direction of the shift were nearly exactly the same.

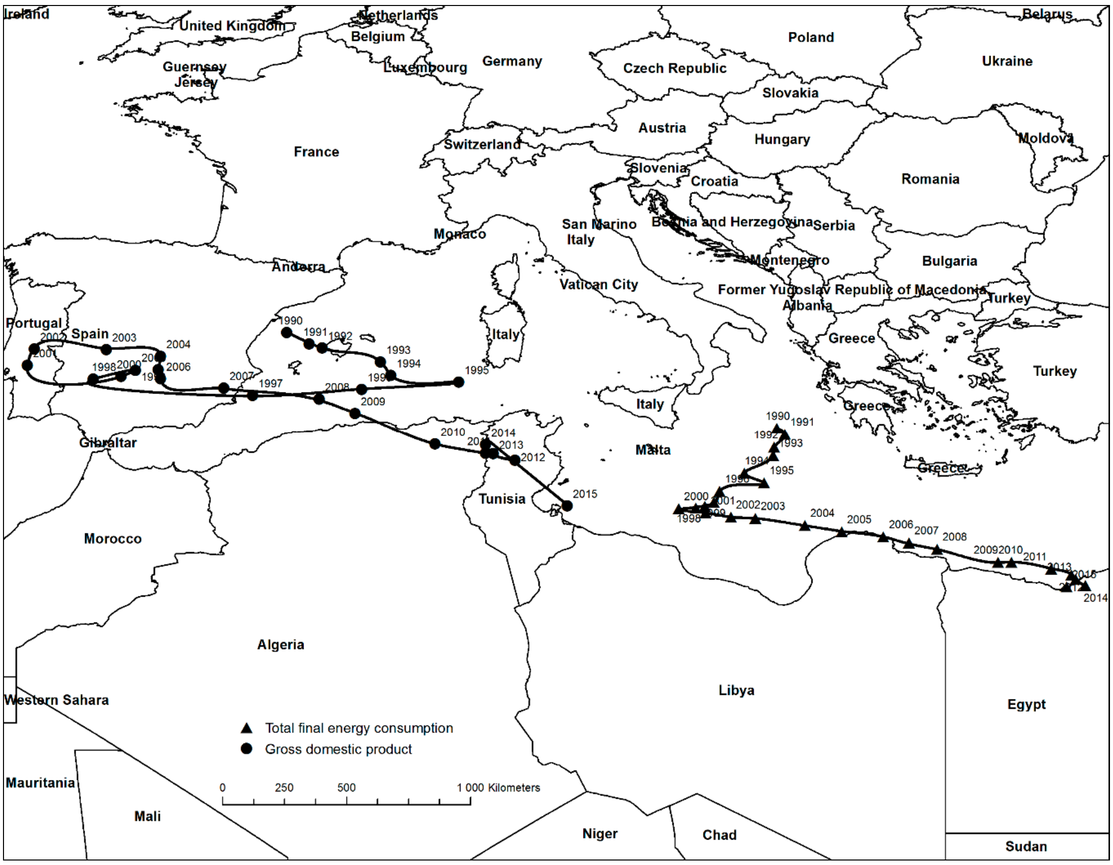

Figure 5. Shift in global economic and energy centres of gravity (1990–2015). Source: own compilation.

Between 1990 and 2015 the energy and economic centres of gravity could be found in the Mediterranean Basin (but here we note it moves from Spain—the Iberian Peninsula—towards Tunis and the eastern coast of the Mediterranean Sea), which refers to the dominance of North. However, this movement towards the southeast indicates the position loss of the Northern Hemisphere and the fact that the developing (emerging) countries (global south) are becoming more and more important.

3.1. Movement of Gravity Centres

To describe the movement of gravity centres the standard of distance is measured. Table 3 shows the results. It can be stated that the movement of economic centres of gravity is much larger (on every continent and every time period) than the movement of energy centres of gravity. Generally, the movement of gravity centres was smaller between 1990 and 2000 than in the second time period (between 2001 and 2015).

Table 3. Weighted standard distance of economic and energy centres of gravity (degree) Source: own calculation.

Region	Time	GDP	TFEC
World	1990–2015	5.90	5.28
	1990–2000	4.22	1.68
	2001–2015	6.08	3.91
Africa	1990–2015	1.30	0.77
	1990–2000	1.16	0.36
	2001–2015	0.97	0.43
Americas	1990–2015	2.65	1.54
	1990–2000	1.49	0.53
	2001–2015	2.65	1.13
Asia	1990–2015	6.60	1.15
	1990–2000	1.80	0.58
	2001–2015	3.38	0.80
Australia	1990–2015	0.46	0.27
	1990–2000	0.31	0.13
	2001–2015	0.42	0.22
Europe	1990–2015	2.36	2.86
	1990–2000	1.91	0.43
	2001–2015	1.96	0.83

3.2. Results of Bi-Dimensional Regression

One of the main objectives of the bi-dimensional regression is to reveal how geometric displacement can be used to get from the point set obtained by the gravitational calculation using GDP to the point set obtained by the gravitational calculation using TFEC. The results presented in Table 4 show a strong correlation between the point set obtained by the gravitational calculation using GDP and TFEC in Asia (the value of it is 0.746), but globally, in America, and in Australia, it is only moderate (0.532, 0.615, and 0.621, respectively) between 1990 and 2015. In Africa and in Europe only a weak positive correlation can be observed (the correlation value for the former is 0.378 and for the latter 0.182). The value of Φ is under 1 (in every case), which means basically a zoom out, but here we compare not spatial forms but only points. Based on the methodology of bi-dimensional regression, Θ is the rotation angle. If $\Theta = 0$, then the XY coordinate system should not be rotated; if it is negative it indicates a clockwise rotation. This latter can be seen for the Americas and Australia, while for the other continents (Asia, Africa, Europe, and the world) the relationship shows an anti-clockwise rotation. The SSR (sum of squares due to regression) is the highest in Asia at over 80% and it has moderate explanation power for the American and Australian continent (similar to the results of the correlation analysis). However, the SSR (the square sum of difference explained by regression) is only 7% in Europe, so the explanatory power of the model is very small and the SSE (sum of squares of errors/residuals that is not explained by the regression) is extremely high (its value is 93.45%). For Africa the SSR is also low (26.52%), while globally it is moderate (48.67%).

Table 4. Two-dimensional regression between the gravitational centres calculated under GDP and total final energy consumption (1990–2015, 1990–2000, 2001–2015). Source: own calculation.

Continent	Time	r	α_1	α_2	β_1	β_2	Φ	Θ	SST (%)	SSR (%)	SSE (%)
World	1990–2015	0.532	24.78	9.40	0.63	0.11	0.64	0.17	100	48.67	51.33
	1990–2000	0.519	20.87	24.93	0.26	0.09	0.27	0.36	100	46.61	53.39
	2001–2015	0.894	24.43	5.06	0.73	0.03	0.73	0.05	100	95.94	4.06
Africa	1990–2015	0.378	14.36	1.36	0.29	0.00	0.29	0.01	100	26.52	73.48
	1990–2000	0.428	17.70	−0.42	0.14	0.11	0.18	0.75	100	33.32	66.68
	2001–2015	0.144	18.20	3.05	0.08	0.00	0.08	−0.01	100	4.09	95.91
Americas	1990–2015	0.615	−51.93	6.01	0.43	−0.09	0.44	−0.21	100	61.41	38.59
	1990–2000	0.522	−68.59	22.80	0.25	−0.01	0.25	−0.02	100	47.00	53.00
	2001–2015	0.852	−56.14	9.87	0.38	−0.07	0.38	−0.18	100	92.47	7.53
Asia	1990–2015	0.746	81.07	21.94	0.15	0.02	0.15	0.11	100	80.28	19.72
	1990–2000	0.366	93.71	10.03	0.08	0.14	0.15	0.11	100	25.06	74.94
	2001–2015	0.841	75.48	26.70	0.19	−0.04	0.19	−0.21	100	91.47	8.53
Australia	1990–2015	0.621	75.67	−8.53	0.47	−0.04	0.47	−0.09	100	62.32	37.68
	1990–2000	0.130	143.15	−16.98	−0.01	−0.08	0.08	0.05	100	3.36	96.64
	2001–2015	0.782	66.24	−10.54	0.53	−0.02	0.53	−0.03	100	84.90	15.10
Europe	1990–2015	0.182	31.11	36.36	0.32	0.04	0.32	0.12	100	6.55	93.45
	1990–2000	0.741	23.12	−26.90	1.60	0.09	1.60	0.06	100	79.66	20.34
	2001–2015	0.531	28.62	41.69	0.21	0.00	0.21	−0.01	100	48.44	51.56

The investigation using these maps allows us to conclude that around 2000 a change of direction took place in the world, which refers to a structural break: until then the economic centre of gravity moved towards the west and the energy centre of gravity shifted towards the southwest. After 2000 both of them turned towards the east. To test the related hypothesis, the Chow Test is applied. The dataset is split into two parts. The H1 hypothesis for the test is that the year 2000 serves as a break point globally, which can be explained by rapid growth in the price of raw materials and by economic prosperity. The examined time period is split into two main parts: the first is from 1990–2000, the second contains the years of 2001–2015. To do the Chow test the pooled-OLS model is applied and we do not suppose the causality direction a priori, so we make our calculations into both directions. The results are shown in Table 5. Based on the results, we can reject the null hypothesis and we accept the presence of a structural break in the year 2000.

Table 5. Chow test for structural break. Source: own calculation.

	Case I: Dependent Variable: logGDP	Case II: Dependent Variable: logTFEC
Test statistic	$F(2, 4977) = 27.2525$	$F(2, 4977) = 14.5053$
p-value	$P(F(2, 4977) > 27.2525) = 0.000$	$P(F(2, 4977) > 14.5053) = 0.000$

Note: Null hypothesis: no structural break.

Based on the results of the Chow test we carried out a two-dimensional regression analysis for both time periods. The results (Table 5) verify that a sharp structural break related to the energy and economic centres of gravity is found at the turn of the millennium. Globally and in the case of the Americas, Asia and Australia the correlation between the two centres of gravity became stronger. In contrast, in the case of Africa and Europe a weakening relationship can be observed (the value of SSR is 4.09% in Africa and 48.44% in Europe); moreover, the relationship between the point sets obtained by the gravitational calculations using GDP and TFEC not only becomes weaker but clearly takes another direction. This is the primary reason for the weak correlation during the whole time period. But the trend of the angle of shifting (Θ) shows no regularity, so—for the time being—in our view the method cannot be applied for the analysis of causality directions between economic growth and energy use.

4. Discussion

It is predicted that global energy use will continue to grow by around a third or so by 2040 and the industrial energy consumption will account for around half of the increase in it [1]. From a geographical view, all of the growth is in emerging economies (mainly in China and India), which account for half of the growth in global energy demand. Significant changes in global energy demand can occur within a short time that affect not only the international trade of fuels and global cash flows but also energy security issues of the developed world. This creates new challenges for global energy systems and governance, with a deepening gap between energy importers and exporters.

Energy security is at the top of the list related to the most urgent energy and foreign policy priorities (in most countries). We believe that understanding the geographies of energy demand, as well as the spatial variation in energy consumption, is critical not only in determining the substitutability of fossil fuel resources but also in energy security issues. This means the uninterrupted physical availability of the energy sources at affordable prices, and having regard for the environment and the principles of sustainability. In the long-term, energy security means all of the investments which, if carried out in time, ensure that supply can meet the demands arising during economic development (having regard to environmental sustainability). In the short-term, this means the ability of energy systems to immediately react to any sudden changes, keeping the balance of demand and supply. The degree of energy security will not be satisfactory if the energy is physically not available or is sold at a price which most role-players cannot afford. The unpredictability of the future and the dynamics of international relations make the planning of energy systems more difficult: potential threats must be identified on the basis of the available (and never complete) information. However, possible responses and assets can be improved through continuous assessments, and the flexibility of the system can be enhanced. Political decision-makers play a key role in energy security; as they are the ones who have information about the whole system, and they are responsible for the synchronization of the activities of people working in the sector.

5. Conclusions

In our study the centre of gravity method (a member of the family of gravity models) and bi-dimensional regression were applied to examine the shift in economic and energy centres of gravity during the period of 1990–2015 in the world and on each of the continents. The basic hypotheses were partly confirmed and the following statements can be made:

- The economic and energy centre of gravity can be found in the Mediterranean Basin, but a slow and gradual shift to the east can be observed. Currently it reflects the dominance of the north, but it marks the decreasing role of the northern hemisphere (position loss) and the greater importance of the developing (emerging) economies (in the southern hemisphere).
- A strong correlation between the point set obtained by the gravitational calculation using GDP and the total final energy consumption is observed between 1990 and 2015 only in Asia. Globally, in the Americas and in Australia and Oceania the strength of the relationship is moderate, while in Africa and in Europe the relationship is much weaker. These results are confirmed by the SSE (the square sum of difference not explained by the regression).
- The year 2000 can be interpreted as a turning point (or as a structural change). After that point the co-movement of the two examined indicators becomes conspicuous. This can be increasingly perceived in the Americas, in Asia, in Australia, and globally. However, in the case of Africa and Europe an opposite and weakening correlation can be observed.

- The application of the gravity model and bi-dimensional regression analysis can be limited to identify the causality directions among these examined variables; further investigation of this topic should be conducted.

This study contributes to apply kindly new approaches and methods (such as centre of gravity method, two-dimensional regression, standard distance) to examine the spatial movements of energy demand and to give additional information about the new geography of energy. In the future this investigation should be developed further. Beyond the national level, the consideration of the regional level is necessary. It would enable us to measure the shifts more accurately and to obtain deeper knowledge about the causality relationship between energy consumption and economic growth.

Author Contributions: Conceptualization: G.T. and T.S.S.; methodology: G.T. and T.S.S.; software: G.T. and T.S.S.; validation: G.T. and T.S.S.; formal analysis: G.T. and T.S.S.; investigation: G.T. and T.S.S.; resources: G.T. and T.S.S.; data curation: G.T. and T.S.S.; writing—original draft preparation: G.T. and T.S.S.; writing—review and editing: G.T. and T.S.S.; visualization: G.T.; supervision: G.T. and T.S.S.; project administration: T.S.S.; funding acquisition: T.S.S.

Funding: This research was supported by project no. EFOP-3.6.2-16-2017-00007, titled "Aspects on the development of intelligent, sustainable and inclusive society: social, technological, innovation networks in employment and digital economy". The project has been supported by the European Union, and co-financed by the European Social Fund and the budget of Hungary.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

References

1. IMF. World Economic and Financial Surveys. World Economic Outlook. Database—WEO Groups and Aggregates Information. 2017. Available online: https://www.imf.org/external/pubs/ft/weo/2017/01/weodata/groups.htm (accessed on 15 September 2018).
2. BP. *Energy Outlook 2018*. 2018. Available online: https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/energy-outlook/bp-energy-outlook-2018.pdf (accessed on 15 September 2018).
3. World Energy Council. World Energy Scenarios 2017. 2017. Available online: https://www.worldenergy.org/wp-content/uploads/2017/05/LAC-Scenarios_Full-Report_FINAL.pdf (accessed on 15 September 2018).
4. Zhang, N.; Lior, N.; Jin, H. The energy situation and its sustainable development strategy in China. *Energy* **2011**, *36*, 3639–3649. [CrossRef]
5. World Bank. World Development Indicators. Database. 2018. Available online: http://databank.worldbank.org/data/reports.aspx?source=world-development-indicators (accessed on 25 September 2018).
6. World Bank. Sustainable Energy 4 All. Database. 2018. Available online: https://datacatalog.worldbank.org/dataset/sustainable-energy-all (accessed on 25 September 2018).
7. Szabó, Z.S. A válság Hatása Kínára, és Peking Gazdaságpolitikai Válaszai. Magyar Tudomány 2010, 4. Available online: http://www.matud.iif.hu/2010/04/08.html (accessed on 6 May 2018).
8. Zhang, Y.; Zhang, J.; Yang, Z.; Li, J. Analysis of the distribution and evolution of energy supply and demand centres of gravity in China. *Energy Policy* **2012**, *49*, 695–706. [CrossRef]
9. Wang, W.; Zhang, M.; Li, P. Exploring temporal and spatial evolution of global energy production and consumption. *Renew. Sustain. Energy Rev.* **2014**, *30*, 943–949. [CrossRef]
10. Duncan, R. The Olduvai Theory—Energy, Population and Industrial Civilization. *Soc. Contract* **2005**, *16*, 6.
11. Stern, D.I.; Cleveland, C.J. *Energy and Economic Growth*; Rensselaer Working Papers in Economics, Encyclopedia of Energy; Academic Press: San Diego, CA, USA, 2004; pp. 35–51.
12. Stern, D.I. The role of energy in economic growth. *Ann. N. Y. Acad. Sci.* **2011**, *1219*, 26–51. [CrossRef]
13. Murphy, D.J.; Hall, C.A.S. Adjusting the economy to the new energy realities of the second half of the age of oil. *Ecol. Model.* **2011**, *223*, 67–71. [CrossRef]
14. Kovács, F. Energiaigények és a világ szénkészletei. *A Miskolci Egyetem Közleménye A sorozat, Bányászat* **2007**, *71*, 63–74. (In Hungarian)
15. Kovács, F. A megújuló energiafajták várható arányai az energiaigények kielégítésében. *A Miskolci Egyetem Közleménye A sorozat, Bányászat* **2007**, *71*, 47–62. (In Hungarian)

16. Lakatos, I.; Lakatosné Szabó, J. A nem Konvencionális Szénhidrogének Jelentősége a XXI. Században. 2008. Available online: http://www.mernokkapu.hu/fileok/2/Koolaj-Foldgaz.pdf (accessed on 8 May 2017). (In Hungarian).
17. Berndt, E.R.; Wood, D.O. Technology, prices and the derived demand for energy. *Rev. Econ. Stat.* **1975**, *3*, 259–268. [CrossRef]
18. Schurr, S.H. Energy Efficiency and Productive Efficiency: Some Thoughts Based on American Experience. *Energy J.* **1982**, *3*, 3–14. [CrossRef]
19. Stern, D.I. Energy Quality. 2009. Available online: http://mpra.ub.uni-muenchen.de/16857/1/MPRA_paper_16857.pdf (accessed on 4 December 2018).
20. Ayres, R.U.; Ayres, L.W.; Warr, B. Exergy, power and work in the US economy, 1900–1998. *Energy* **2003**, *28*, 219–273. [CrossRef]
21. Ayres, R.U.; Warr, B. Accounting for growth: The role of physical work. *Struct. Chang. Econ. Dyn.* **2005**, *16*, 181–209. [CrossRef]
22. Akizu, O.; Urkidi, L.; Bueno, G.; Lago, R.; Barcena, I.; Mantxo, M.; Basurko, I.; Lopez-Guede, J.M. Tracing the emerging energy transitions in the Global North and the Global South. *Int. J. Hydrogen Energy* **2017**, *42*, 18045–18063. [CrossRef]
23. Arto, I.; Capellán-Pérez, I.; Lago, R.; Bueno, G.; Bermejo, R. The energy requirement of a developed world. *Energy Sustain. Dev.* **2016**, *33*, 1–13. [CrossRef]
24. Munkácsy, B. *Energiaföldrajz és Energiatervezés*; Eötvös Loránd Tudományegyetem, Természettudományi Kar, Földrajztudományi Központ, Környezet- és Tájföldrajzi Tanszék: Budapest, Hungary, 2018; 135p, Available online: http://munkacsy.web.elte.hu/energiafoldrajz%20tankonyv.pdf (accessed on 15 May 2018). (In Hungarian)
25. Calvert, K. From "energy geography" to "energy geographies": Perspectives on a fertile academic borderland. *Prog. Hum. Geogr.* **2016**, *40*, 105–125. [CrossRef]
26. Kraft, J.; Kraft, A. On the relationship between energy and GNP. *J. Energy Dev.* **1978**, *3*, 401–403.
27. Sorrell, S.; Dimitropoulos, J. *UKERC Review of Evidence for the Rebound Effect*; Technical Report 5: Energy, productivity and economic growth studies; UKERC: London, UK, 2007; 192p. Available online: http://ukerc.rl.ac.uk/UCAT/PUBLICATIONS/UKERC_Review_of_Evidence_for_the_Rebound_Effect_-_Technical_Report_5_Energy,_productivity_and_economic_growth_studies.pdf (accessed on 10 April 2019).
28. Jin, S. The effectiveness of energy efficiency improvement in a developing country: Rebound effect of residential electricity use in South Korea. *Energy Policy* **2007**, *35*, 5622–5629. [CrossRef]
29. Tsani, S.Z. Energy consumption and economic growth: A causality analysis for Greece. *Energy Econ.* **2010**, *32*, 582–590. [CrossRef]
30. Warr, B.; Ayres, R.; Eisenmenger, N.; Krausmann, F.; Schandl, H. Energy use and economic development: A comparative analysis of useful work supply in Austria, Japan, the United Kingdom and the US during 100 years of economic growth. *Ecol. Econ.* **2010**, *69*, 1904–1917. [CrossRef]
31. Cleveland, C.J.; Kaufmann, R.K.; Stern, D.I. Aggregation and the role of energy in the economy. *Ecol. Econ.* **2000**, *32*, 301–317. [CrossRef]
32. Nagy, G. A gravitációs modell felhasználásának lehetőségei a várostérségek lehatárolásában. *Területi Stat.* **2011**, *6*, 656–673. (In Hungarian)
33. Kincses, Á.; Tóth, G. Gravitációs modell alkalmazása a térszerkezet vizsgálatára. Területi Statisztika 2012, 52, 479–491. *Területi Statisztika* **2012**, *52*, 479–491. (In Hungarian)
34. Quah, D. The global economy's shifting centre of gravity. *Glob. Policy* **2011**, *2*, 3–9. [CrossRef]
35. Klein, L.R. Measurement of a shift in the world's centre of economic gravity. *J. Policy Model.* **2009**, *31*, 489–492. [CrossRef]
36. Grether, J.; Mathys, N.A. Is the world's economic centre of gravity already in Asia? *Area* **2010**, *42*, 47–50. [CrossRef]
37. Fesharaki, F. Asia as the centre of gravity of the world energy system. *Energy* **1996**, *21*, 999–1003. [CrossRef]
38. UN. *World Economic Situation and Prospects*; UNCTAD: New York, NY, USA, 2017; Available online: https://www.un.org/development/desa/dpad/wp-content/uploads/sites/45/publication/2017wesp_full_en.pdf (accessed on 15 September 2018).
39. Nemes Nagy, J. Spatial gravity centres of the dynamics and the crisis in Hungary. *Hung. Stat. Rev.* **2002**, *80*, 75–85.

40. Tóth, G.; Nagy, Z. The world's economic centre of gravity. *Reg. Stat.* **2016**, *6*, 177–180. [CrossRef]
41. Jenness, J. Weighted Mean of Points v. 1.2c. 2004. Available online: http://www.jennessent.com/arcview/weighted_mean.html (accessed on 23 November 2018).
42. Durocher, S.; Leblanc, A.; Skala, M. The projection median as a weighted average. *J. Comput. Geom.* **2017**, *8*, 78–104. [CrossRef]
43. Tobler, W.R. Map Transformations of Geographic Space. Ph.D. Thesis, University of Washington, Seattle, WA, USA, 1961.
44. Tobler, W.R. Computation of the Correspondence of Geographical Patterns. *Pap. Reg. Sci. Assoc.* **1965**, *15*, 131–139. [CrossRef]
45. Tobler, W.R. A Computer Model Simulating Urban Growth in the Detroit Region. *Econ. Geogr.* **1970**, *46*, 234–240. [CrossRef]
46. Tobler, W.R. Comparisons of Plane Forms. *Geogr. Anal.* **1978**, *10*, 154–162. [CrossRef]
47. Tobler, W.R. Bidimensional Regression. *Geogr. Anal.* **1994**, *26*, 187–212. [CrossRef]
48. Tobler, W.R. On the First Law of Geography: A Reply. *Ann. Assoc. Am. Geogr.* **2004**, *94*, 304–310. [CrossRef]
49. Friedman, A.; Kohler, B. Bidimensional Regression: Assessing the Configural Similarity and Accuracy of Cognitive Maps and Other Two-Dimensional Data Sets. *Psychol. Methods* **2003**, *8*, 468–491. [CrossRef]
50. Dusek, T. Kétdimenziós regresszió a területi kutatásokban. *Területi Stat.* **2011**, *51*, 11–22. (In Hungarian)
51. ESRI Developer Network. Standard Distance (Spatial Statistics). 2018. Available online: http://edndoc.esri.com/arcobjects/9.2/net/shared/geoprocessing/spatial_statistics_tools/standard_distance_spatial_statistics_.htm (accessed on 2 April 2018).
52. Ramanathan, R. *Bevezetés az Ökonometriába Alkalmazásokkal*; Panem Kiadó: Budapest, Hungary, 2003. (In Hungarian)
53. Szlávik, J.; Sebestyén Szép, T. Delinking of energy consumption and economic growth in the Visegrad group. *Geogr. Tech.* **2017**, *12*, 139–149. [CrossRef]
54. Weiner, C. *Az Állam Szerepe az Orosz Gazdaságban*; MTA Közgazdaság- és Regionális Tudományi Kutatóközpont Világgazdasági Intézet: Budapest, Hungary, 2016; Available online: http://real.mtak.hu/44950/1/MT_119_Weiner.pdf (accessed on 5 May 2018).
55. Moshiri, S. The effects of the energy price reform on households consumption in Iran. *Energy Policy* **2015**, *79*, 177–188. [CrossRef]
56. Brzezinski, Z. *The Grand Chessboard: American Primacy and Its Geostrategic Imperatives*, 2nd ed.; Basic Books: New York, NY, USA, 2016; 316p.
57. IEA. Key World Energy Statistics 2018. 2018. Available online: https://www.iea.org/publications/freepublications/publication/KeyWorld2017.pdf (accessed on 5 May 2018).
58. Simon, G., Jr. Reform és növekedés Kínában. *Közgazdasági Szle* **2001**, *XLVIII*, 673–692. (In Hungarian)