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Energy Efficiency as a Way to Ecological Safety: Evidence From Russia

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ABSTRACT

The paper proposes the link between effective use of energy and reduction of carbon emissions at the case of Russia. A number of energy efficiency indicators are reviewed and calculated. Deterministic analysis is conducted to identify what factors influence carbon intensity the most. The analysis has shown that increasing energy intensity causes a much greater increase in carbon intensity. This paper adopts the method of chain substitutions to calculate the contribution of each factor to the changes in the carbon intensity over a period of time. Therefore, it must be the ultimate goal to achieve a sustainable economy by consuming less energy which in its turn will lead to less CO2 emission.

Keywords: Energy Consumption, Energy Efficiency, Carbon Intensity, Method of Chain Substitutions
JEL Classifications: Q40, Q43, O44, O52

1. INTRODUCTION

As many years of experience have shown, ecology and energy consumption are quite closely connected with each other. After all, it is undeniable that the irrational use of natural resources has a negative impact on the environment (Shvartsburg et al., 2017). To date, human activity has already led to a devastating impact on the environment, and energy efficiency in modern conditions is the only hope for changes for the better. The global scale of transformation will be achieved only when everyone starts to spend energy resources carefully and economically. In the near future, the use of alternative energy sources and widespread energy conservation will make it possible to ensure a gentle attitude to nature.

Nowadays, most countries include energy efficiency in their public policy agendas (Sezgin, 2013). The importance of energy efficiency as a policy objective relates to the benefits to commercial, industrial competitiveness and energy security, as well as increasingly to environmental benefits such as the reduction of CO2 emissions (Gillingham and Palmer, 2014).

The active operation and development of industrial and energy enterprises at a fairly rapid pace leads to a number of environmental problems, and energy efficiency could partly contribute to their resolution. The adoption of a program for the efficient use of resources at the state level was an important step towards addressing environmental priorities, and energy conservation is the most important component of this process. The ecological state largely depends on how productively the energy conservation technologies will be implemented. Thus, a systematic approach should be applied to the problems of ecology and energy conservation, taking into account the proportional impact of environmental health in the region on all processes of society (Fontana et al., 2013).

In this context, it is advisable to analyze the energy efficiency which in its turn will help to understand what carbon intensity depends on.

2. LITERATURE REVIEW

Today, the vast majority of countries is committed to environmental protection, and energy saving is not the only way to achieve the desired result. The use of renewable energy sources is now considered a priority in many countries. Such sources are more affordable and safe to use than traditional energy sources.

The most popular and frequently used alternative energy sources are solar panels, wind power generators, and hydro turbines. In terms of power generation, they are not in many ways inferior to widely known and used sources of energy resources, and sometimes exceed them in various parameters, but their efficiency is much higher. According to experts, renewable energy sources have a phenomenal potential, while they do not have a harmful impact on the environment, and energy conservation in the case of a full transition to alternative energy will lose some of its relevance (Ostrojnaya, 2018).

But the most optimistic forecasts promise a complete transition to alternative energy sources not earlier than in 30-40 years, while traditional sources are used, the environment suffers from this, and energy conservation is vital for the further existence of mankind.

Patterson (1996) reviewed and classified a number of indicators to monitor energy efficiency. In his paper he focused mainly on energy efficiency and its methodological problems.

Ang (2006) examined some classical indicators and composite efficiency index.

It was found that energy consumption is often a key determinant of CO_2 emissions. It is therefore worthwhile to examine the nexus between energy efficiency and CO_2 emissions. In this strand, this relationship was examined in single country study for the USA over 1960-2004 (Soytas et al., 2007) and for China over 1960-2007 (Zhang and Cheng, 2009).

The results of studies on the relationship between CO_2 emissions, energy consumption, and real gross domestic product (GDP) differ from country to another and vary depending to the used methodology. It is difficult to succinctly clarify these variations. If we consider the relationship between energy consumption and CO_2 emissions, then CO_2 emissions can increase through more energy consumption. For example, Belloumi (2009) found this relationship for Tunisia; Ozturk and Acaravci (2010) - for Turkey.

Also, based on panel error-correction model, Arouri et al. (2012) have tested the relationship between CO_2 emissions, energy consumption, and real GDP for 12 Middle East and North African Countries (MENA) over the period 1981-2005. They showed that the real GDP exhibits a quadratic relationship with CO_2 emissions for the region as a whole. The econometric relationships derived in this study suggest that future reductions in carbon dioxide emissions per capita might be achieved at the same time as GDP per capita in the MENA region continues to grow.

Pao and Tsai (2010) examined that causal relationship between pollutant emission, energy consumption and output for BRIC countries over 1971-2005, except for Russia (1990-2005). They used quadratic panel vector error correction model that indicated that there are energy consumption–emissions bidirectional strong causality and energy consumption–output bidirectional long-run causality, along with unidirectional both strong and short-run causalities from emissions and energy consumption, respectively, to output.

The results of Omri (2013) for 14 MENA countries support the occurrence of unidirectional causality from energy consumption to CO_2 emissions without any feedback effects.

The most recent studies of Bhattacharya et al. (2017) for 85 developed and developing countries over the period 1991-2012, Tiba et al. (2016) for 12 middle-income and 12 high-income countries over 1990-2011, Sinha (2016) for 139 Indian cities over the period 2001-2013 used energy to explain pollution.

Menegaki and Arminen (2019) report that ensuing pollution has not yet reached a maximum point. Taking everything mentioned above into consideration, it is a question of primary importance to determine what factors affect carbon emissions the most so that policy-makers can improve their strategies.

3. METHODS

The research uses the time series from Thomson Reuters Datastream at the period from 2003 to 2017 in Russia.

The main factors needed for calculating energy efficiency indicators are, as mentioned above, primary energy consumption and GDP. The former has shown a slower increase than the latter.

National energy efficiency measurements and monitoring have become important components of energy strategy in many countries, especially energy deficient ones. With substantial increases oil prices in the world (Mikhaylov, 2018a; Mikhaylov, 2018b) many countries have recognized the need to understand whether energy is consumed effectively in their economies and to increase energy efficiency. To serve these purposes, appropriate energy efficiency indicators have been developed and applied so that any efficiency changes that have taken place can be quantitatively expressed (Nyangarika et al., 2018; Nyangarika et al., 2019a; Nyangarika et al., 2019b).

Energy efficiency is a generic term, and there is no single quantitative indicator of "energy efficiency." Instead, a number of indicators need to be relied upon to quantify changes in energy efficiency. In general, energy efficiency refers to the use of less energy to produce the same amount of services or useful output (Mikhaylov, 2019; Mikhaylov et al., 2018).

The problem of how to accurately determine the useful output and the energy input has led to a number of indicators to monitor changes in energy efficiency. It is worth noting that the useful output of the process does not necessarily have to be the energy output. It may be a ton of product or some other physically defined output, or it may be the output enumerated in terms of market prices (Patterson, 1996).

The most commonly used aggregate to measure nation's energy efficiency (η) is the *energy-GDP ratio* (*energy intensity*).

$$\eta = \frac{E}{Y} \tag{1}$$

Where E is the primary energy consumption and Y is GDP.

It is assumed that primary energy is used in the creation of the GDP as this is the only way that GDP is consistently related to the energy consumed for its creation (Gvozdenac-Urosevic, 2010).

The exchange-rate-converted GDP tends to exaggerate the real income differences between the developing countries and industrial countries. That is why the purchasing power parity method of equivalencing GDP is recommended to be used for more realistic and valid evaluation of national economies (Gerarden et al., 2015).

Calculated at the annual level, energy-GDP ratio can show short term and long term trends (Wilson et al., 1994). The decline of this ratio shows on the average reduced necessary energy for the generation of national output units. This is considered a desirable development.

The *energy productivity ratio* (P) is the reciprocal of the energy-GDP ratio:

$$P = \frac{Y}{E} \tag{2}$$

Where E is the primary energy consumption and Y is GDP.

The more goods and services an economy produces per unit of energy, the more productive or energy efficient it is said to be.

The energy productivity ratio is seen as a mechanism to focus on the productive use of energy as a complementary measure to the orthodox capital and labour productivity ratios used in economic analysis.

The uncritical use of the energy productivity ratio can lead to misleading conclusions. For example, the energy efficiency coefficient may decrease only because energy replaces labor, and not because of any deterioration in technical energy efficiency. To solve this analytical problem, the analyst can calculate the *marginal energy productivity* (MP) coefficient using standard econometric modeling methods.

$$MP = \frac{\Delta Y}{\Delta E} \tag{3}$$

This ratio measures the marginal effect on output by increasing the energy input (ΔE) by one unit.

The *energy coefficient* (C) for a given period is defined as the ratio of the annual growth rate of primary energy consumption to the annual growth rate of GDP.

$$C = \frac{(E_2 - E_1) - 1}{(Y_2 - Y_1) - 1} \tag{4}$$

Where $Y_2 - Y_1$ is the GDP growth.

Unlike the energy–GDP ratio, the series is often unstable and cannot be always interpreted. Provided the energy consumption growth is significant and the one of GDP is not, the coefficient is either a large positive or negative number, which has little practical value as an energy efficiency indicator. The coefficient can be used if both energy consumption and GDP show positive growth. If these factors move in different directions, the interpretation of the indicator becomes complicated.

An energy coefficient less than unity is generally preferred, since growth in energy consumption is more slowly than that of GDP. Earlier studies have found that the energy coefficient for countries in the early stage of development tends to be greater than unity, it drops to unity for countries in the final stage of industrialization, and drops further to below unity for countries in the post-industrialization phase.

The carbon intensity indicator monitors countries' efforts to reduce CO2 emissions. CO2 emissions are largely a by-product of energy production and use. They account for the largest share of greenhouse gases associated with global warming. The major part of CO2 is released as a result of combustion processes when fossil fuels such as coal, oil and gas are burned, usually in order to produce energy. CO2 is also released as part of certain industrial processes, for example in cement production, and in the waste incineration process (Gillingham et al., 2009).

Continued growth of greenhouse gas emissions at or above the current rates can cause further warming and induce many changes in the global climate system. As CO2 is the major component of greenhouse gases, monitoring CO2 emissions is particularly important. Rising CO2 emissions lead to increases in the concentration of carbon dioxide in the atmosphere, higher global temperatures, rising sea levels and other sizable adverse impacts on the animals, plants and people inhabiting the planet (Feng et al., 2013). Several international conventions and agreements aim to halt and reverse the effects of emissions, the United Nations Framework Convention on Climate Change and its Kyoto Protocol being the most prominent.

Emissions intensity the level of greenhouse gas emissions per unit of economic output is a composite indicator of two other major factors contributing to a country's emissions profile, namely energy intensity and fuel mix (Baumert et al., 2005).

Carbon intensity = Energy intensity × Fuel mix

$$\frac{CO2}{Y} = \frac{E}{Y} \times \frac{CO2}{E} \tag{5}$$

CO2 emissions intensity is a function of two variables. The first variable is energy intensity, or the amount of energy consumed per unit of GDP. This reflects both a country's level of energy efficiency, as it was mentioned above, and its overall economic structure, including the carbon content of goods imported and exported. An economy dominated by heavy industrial production, for instance, is more likely to have higher energy intensity than one where the service sector is dominant, even if the energy efficiencies within the two countries are identical. Likewise, a country that relies on trade to acquire (import) carbon-intensive goods will when all other factors are equal have a lower energy intensity than those countries that manufacture those same goods for export. Energy-intensity levels are not well correlated with economic development levels. Intensities in developing countries tend to be somewhat higher than in industrialized countries, owing largely to the fact that developing countries generally have a higher share of their GDP coming from energy-intensive manufacturing industries, such as basic metals. Industrialized countries, on the other hand, have greater shares of their economies comprised of lower-carbon service sectors.

The second component of emissions intensity is fuel mix or, more specifically, the carbon content of the energy consumed in a country. Coal has the highest carbon content, followed by oil and then natural gas. Accordingly, if two nations are identical in energy intensity, but one relies more heavily on coal than the other, its carbon intensity will be higher.

This paper proposes the method of chain substitutions to calculate the contribution of each factor to the changes in the carbon intensity over a period of time.

$$\text{Carbon intensity}_0 = \text{Energy Intensity}_0 \times \text{Fuel Mix}_0$$

$$\text{Carbon intensity}_\eta = \text{Energy Intensity}_0 \times \text{Fuel Mix}_1$$

$$\text{Carbon intensity}_1 = \text{Energy Intensity}_1 \times \text{Fuel Mix}_1 \quad (6)$$

Where Carbon intensity$_0$, Energy Intensity$_0$, Fuel Mix$_0$ are base figures; Carbon intensity$_1$, Energy Intensity$_1$, Fuel Mix$_1$ are actual figures; Carbon intensity$_\eta$ and Carbon intensity$_{FM}$ are interim results to identify the influence of energy intensity and fuel mix correspondingly.

Total change Δ Carbon intensity = Carbon intensity$_1$ – Carbon intensity$_0$ consists of the sum of changes in the resulting indicator due to changes in each factor at fixed values of other factors:

$$\Delta \text{ Carbon intensity} = \Delta \text{ Carbon intensity}_\eta + \Delta \text{ Carbon intensity}_{FM}$$

$$\Delta \text{ Carbon intensity}_\eta = \text{Carbon intensity}_\eta - \text{Carbon intensity}_0$$

$$\Delta \text{ Carbon intensity}_{FM} = \text{Carbon intensity}_1 - \text{Carbon intensity}_\eta$$

Factors can have compounding or offsetting effects on changes in emissions. Relatively small changes in factors can result in a large change in carbon intensity when all the factors change in the same direction. On the other hand, large changes in one factor can be offset by opposing changes in other factors, resulting in only a small change in carbon intensity.

Emissions intensities, at least with respect to energy and industrial emissions, are influenced primarily by shifts in energy intensity, economic structure, and fuel mix. It follows that emission intensities are not directly correlated with changes in activity levels (GDP and population). Even in the event of major GDP changes, changes in intensity levels may be modest.

Table 1: Energy Efficiency indicators

Date	Primary energy consumption (million tons of oil equivalent)	GDP (billions U.S.dollar)	GDP PPP (billions U.S. dollar)	Energy/GDP	Energy/GDP PPP	Energy productivity ratio (PPP $ of GDP/1kg)	Marginal energy productivity ratio (PPP $ of GDP/1kg)	Energy coefficient
June 30,2003	634,895	1918,7	2324,43	0,331	0,273	3,661	-	-
June 30, 2004	640,591	2143,7	2491,23	0,299	0,257	3,889	29,284	0,125
June 30, 2005	640,348	2318,9	2650,08	0,276	0,242	4,138	−653,704	−0,006
June 30, 2006	668,571	2671,2	2866,15	0,250	0,233	4,287	7,656	0,541
June 29, 2007	673,051	3032,9	3110,78	0,222	0,216	4,622	54,605	0,079
June 30, 2008	676,566	3524,1	3274,03	0,192	0,207	4,839	46,444	0,100
June 30, 2009	644,648	2463,7	3017,97	0,262	0,214	4,682	8,022	0,603
June 30, 2010	668,195	2560,3	3153,89	0,261	0,212	4,720	5,772	0,811
June 30, 2011	691,738	2986,9	3284,38	0,232	0,211	4,748	5,543	0,852
June 29, 2012	694,698	2665,2	3404,45	0,261	0,204	4,901	40,564	0,117
June 28, 2013	683,939	2677,2	3465,23	0,255	0,197	5,067	−5,649	−0,867
June 30, 2014	689,615	2595,9	3490,82	0,266	0,198	5,062	4,508	1,124
June 30, 2015	676,779	1548,9	3392,1	0,437	0,200	5,012	7,691	0,658
June 30, 2016	689,553	1348,1	3388,59	0,511	0,203	4,914	−0,275	−18,241
June 30, 2017	698,251	1474,2	3440,97	0,474	0,203	4,928	6,022	0,816

Source: Calculated by the author according to Thomson Reuters data stream. GDP: Gross domestic product

Table 2: Analysis of CO2 emissions

Date	Primary energy consumption (million tons of oil equivalent)	GDP PPP: (billions U.S. dollar)	Emissions - carbon dioxide: Million ton	Fuel mix	Energy intensity	Carbon intensity
June 30, 2003	634,895	2324,43	1495,21	2,355	0,273	0,643
June 30, 2004	640,591	2491,23	1490,3	2,326	0,257	0,598
June 30, 2005	640,348	2650,08	1466,6	2,290	0,242	0,553
June 30, 2006	668,571	2866,15	1535	2,296	0,233	0,536
June 29, 2007	673,051	3110,78	1528,1	2,270	0,216	0,491
June 30, 2008	676,566	3274,03	1554,28	2,297	0,207	0,475
June 30, 2009	644,648	3017,97	1448,5	2,247	0,214	0,480
June 30, 2010	668,195	3153,89	1489,8	2,230	0,212	0,472
June 30, 2011	691,738	3284,38	1555,75	2,249	0,211	0,474
June 29, 2012	694,698	3404,45	1570,99	2,261	0,204	0,461
June 28, 2013	683,939	3465,23	1524,35	2,229	0,197	0,440
June 30, 2014	689,615	3490,82	1533,32	2,223	0,198	0,439
June 30, 2015	676,779	3392,1	1495,49	2,210	0,200	0,441
June 30, 2016	689,553	3388,59	1510,5	2,191	0,203	0,446
June 30, 2017	698,251	3440,97	1525,34	2,185	0,203	0,443

Source: Calculated by the author according to Thomson Reuters Datastream. GDP: Gross domestic product

Table 3: Analysis of the influence of changes in energy intensity and fuel mix on carbon intensity

Date	June 30, 2003	June 30, 2017	Change	The method of chain substitutions			Contribution to carbon intensity change
				I	II	III	
Energy intensity	0,273	0,203	−0,070	0,273	0,203	0,203	−0,165
Fuel mix	2,355	2,185	−0,171	2,355	2,355	2,185	−0,035
Carbon intensity	0,643	0,443	−0,200	0,643	0,478	0,443	−0,200

Source: Calculated by the author

4. RESULTS

As we see from Table 1, the energy-GDP ratio calculated using the exchange-rate-converted GDP has greater values than the one that considers the purchasing power method. Calculating both indicators helps to avoid misleading conclusions as there are differences in real income between different countries, and, therefore, GDP based on purchasing power parity shows more reliable data (Gvozdenac-Urosevic, 2010).

This way, the energy-GDP ratio showed that there was a significant increase over the period of years, while when considering the purchasing power we see that there was a decline in the energy intensity. Thus, it can be said that the country needed less energy to produce the same amount of services or useful output.

As a reciprocal indicator to the energy-GDP ratio, the energy productivity ratio has shown a rise in its value which generally means a productive use of energy. However, it cannot be considered as an axiom, because the rise could be caused by labor or capital substitution for energy.

To capture how primary energy consumption directly affects production output, it was necessary to calculate marginal product of energy. That is, the extra output obtained by employing one extra unit of energy. The interpretation of the indicator may be complicated if energy consumption and GDP move in different directions.

The coefficient 0.816 in year 2017 indicates that GDP (PPP) increases by 0.816% when there is a 1% increase in energy consumption. This indicates that an increase in energy consumption tends to promote economic growth (Shahbaz et al., 2013; Wong et al., 2013).

One of the drivers of carbon emissions, is carbon intensity, i.e., CO2 emitted per unit of energy consumed.

Fuel Mix and Carbon Intensity are presented in Table 2.

Both Fuel Mix and Energy Intensity has been decreasing over the period of years, thereby reducing carbon intensity. To identify which variable carbon intensity depends most the two-factor multiplicative model was analyzed (Table 3).

The deterministic factor analysis has shown that the change of Energy Intensity by 0,070 caused a much greater change in carbon intensity (by 0,165), whereas the influence of fuel mix change was smaller than the change itself. The case is also true for the year-to-year analysis.

5. CONCLUSION

As a result, advances in the energy efficiency can change the amount of CO2 emitted per unit of energy consumed to a greater extent than fuel mix. Therefore, the efforts of the authorities should be more focused on ensuring energy-efficient production. It should be considered as a flotation ring that would save mankind from the ultimate environmental catastrophe.

In addition, as energy efficiency directly depends on GDP, a decline in the former can be achieved by economic growth, i.e., annual percentage growth rate of GDP.

Such a perspective inevitably brings to the fore a new relationship between environmental and energy policies, a perspective that intertwines both, one in which the former is increasingly reduced to the latter. This can be done by more effective and efficient use of resources and utilization of renewable energy sources.

The issues of ecology and energy efficiency are considered today in all regional energy development programs, where one of the main priorities is to preserve the environment, and energy efficiency is given priority (DeCanio, 1998; Brown, 2001).

An integrated approach to ecology and energy efficiency will allow everyone to get their advantages.

An ordinary citizen will be able to pay less on the bills for the energy resources spent by him (Branch, 1993), and industrial enterprises, both large and small, will reduce the cost of the final product. The state will be able to direct the amounts saved through the rational use of energy resources to the development of the economy and social sphere, and most importantly – nature will be able to take a little break from the continuous impact of people.

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