Article

Changes in Energy Consumption, Economic Growth and Aspirations for Energy Independence: Sectoral Analysis of Uses of Natural Gas in Ukrainian Economy

Olexandr Yemelyanov ¹, Anastasiya Symak ¹, Tetyana Petrushka ¹, Olena Zahoretska ¹, Myroslava Kusiy ², Roman Lesyk ^{3,4} and Lilia Lesyk ^{1,*}

¹ Department of Business Economics and Investment, Institute of Economics and Management, Lviv Polytechnic National University, 5 Metropolian Andrey str., Building 4, 79005 Lviv, Ukraine; Oleksandr.Yemelianov@lpnu.ua (O.Y.); asimak@ukr.net (A.S.); petrushkat24@ukr.net (T.P.); zagoreckao@gmail.com (O.Z.)

² Department of Applied Mathematics and Mechanics, Institute of Civil Defense, Lviv State University of Life Safety, 35, Kleparivska St., 79007 Lviv, Ukraine; kusijmiroslava@gmail.com

³ Department of Pharmaceutical, Organic and Bioorganic Chemistry, Danylo Halytsky Lviv National Medical University, Pekarska 69, 79010 Lviv-10, Ukraine; dr_r_lesyk@org.lviv.net

⁴ Department of Public Health, Dietetics and Lifestyle Disorders, Faculty of Medicine, University of Information Technology and Management in Rzeszow, Sucharskiego 2, 35-225 Rzeszow, Poland

* Correspondence: lilia.lesyk@gmail.com; Tel.: +380-322-582545

Received: 26 August 2019; Accepted: 10 December 2019; Published: 11 December 2019

Abstract: The main objective of the research is to assess the ability of the Ukrainian economy and its individual industries to ensure, in the conditions of economic growth, a stable reduction of natural gas consumption and, consequently, to reduce dependence on its imports. Six types of relationships were identified between the change in sectoral added value and the change in the consumption of certain energy resources, in particular natural gas. The conditions are established under which the growth of sectoral added value is accompanied by a decrease in the consumption of certain energy resources. The index of sectoral efficiency of the use of certain energy resources was proposed and a model of the decomposition of the growth rate of this indicator was constructed. Quantitative indicators of measuring economic barriers on the way to introduction of energy-saving technologies are presented. Conditions under which economic growth is accompanied by a decrease in the level of dependence of the economy on imports of energy resources are modeled. The dynamics of natural gas consumption by sectors of the Ukrainian economy is analyzed. It is proved that reduction of natural gas consumption due to increased energy efficiency occurs mainly in industries with an average value of share of the cost of purchasing this energy in the total operating expenses. An estimation is undertaken of the possibility of achieving independence of the Ukrainian economy from the import of natural gas in different scenarios of changing main parameters that determine the probability of such an achievement.

Keywords: economic growth; energy consumption; energy independence; natural gas; energy saving

1. Introduction

Nowadays, many countries face the problem of dependence on imports from foreign energy sources. This dependence may negatively affect the trade balance of the countries and the exchange rate of national currencies. In addition, the high share of imported energy in the structure of energy

consumption causes a risk of economic losses due to disruption of energy supplies. Finally, countries' dependence on imported energy can have political consequences if this dependence is used as an instrument of political pressure on the governments of those countries that import energy sources. In this regard, in recent years, many countries, in particular European Union (EU) countries [1] and the United States [2,3], have developed and have implemented government programs for the purpose of reducing their dependence on imported energy supplies.

The achievement of energy independence is complicated if the economy is growing, because such growth may require additional energy resources. Consequently, there is a certain contradiction between the aim of reducing dependence of the economy on imported energy and the necessity of ensuring stable economic growth. However, in most countries, the possibility of such an increase is limited or absent. Therefore, reducing power consumption, in particular through the development of renewable (green) energy [4] and improving energy efficiency [5], are crucial for achieving energy independence.

Natural gas plays an important role among all types of energy resources, the import of which countries are trying to reduce. This is due to the fact that the supply of this type of energy is difficult to diversify and import prices are often very high. On the other hand, natural gas is currently one of the main sources of energy for many countries, particularly EU countries [6].

Ukraine also belongs to the list of countries for which the achievement of independence from natural gas imports is particularly relevant. Previously, this country satisfied a significant share of demand for natural gas by imports from Russian Federation. However, since 2014, as a result of the military-political conflict [7,8], relations between Ukraine and Russian Federation have become much more complicated. Ultimately, this resulted in the termination of imports of natural gas from the Russian Federation with simultaneous reorientation to its purchase from EU countries. At the same time, the situation is complicated by the fact that the government of Ukraine has temporarily lost control over part of the territory of the country, where there are rich deposits of natural gas.

The risk of possible interruptions in the supply of natural gas to Ukraine is quite high, and its import price significantly exceeds the cost of extracting its own natural gas. Therefore, the Ukrainian government has set the goal of achieving energy independence from imports of natural gas [9]. To do this, the government planned to reduce natural gas consumption, as well as to increase its own production [10]. In particular, a state support program of measures to improve energy efficiency in the residential sector [11,12] was launched in order to reduce natural gas consumption in Ukraine. The possibility of implementing such a program for commercial consumers of natural gas is also being considered. However, although the share of imports of natural gas in the total demand of the Ukrainian economy generally tends to decrease, this share in 2018 remained at about 30%. This, in particular, is due to the fact that the volume of natural gas consumption in the Ukrainian economy remains too important. Taking this into account, the main goal of our research was to assess the ability of the Ukrainian economy and its individual industries to ensure a stable reduction in natural gas consumption and, consequently, to reduce dependence on its imports in the context of economic growth. During the problem solving, we received some results that contain scientific novelty.

Firstly, the methodological principles for assessing the economy's ability to sustainably reduce energy consumption and to weaken energy dependence in conditions of economic growth were improved. In particular, six types of relationships have been identified between the change in sectoral value added and the change in the consumption of natural gas. The conditions under which the growth of sectoral added value is accompanied by a decrease in the consumption of energy resources are determined. The indicator of sectoral efficiency of the use of energy resources as the ratio of sectoral value added to the volumes of consumption of this energy resource is proposed. The model of decomposition of the growth rate of the sectoral level of energy resource efficiency is constructed. Quantitative indicators of measuring economic barriers on the way to implementation of energy-saving technologies are presented. The conditions under which economic growth is accompanied by a decrease in the level of energy dependence of the country's economy on imports of energy resources are modulated.

Secondly, due to the empirical analysis, we estimated the influence of factors on the change in the volume of natural gas consumption by the industries of Ukraine and on the change of the sectoral level of the efficiency of the use of natural gas. It was established that the reduction of natural gas consumption due to increased energy efficiency mainly occurs in the sectors with an average value of the share of the cost of purchasing this energy in total operating expenses. The necessity of strengthening of the state financial support for the implementation of measures for the thermo-modernization of residential buildings by households was proved.

Thirdly, an assessment of the possibility for Ukraine to achieve independence from imports of natural gas with different scenarios of changing the main parameters that determine the probability of such an achievement was proposed in the article. Accordingly, the recommendations that can be taken into account when developing and correcting the state energy strategy are presented.

Achievement of the goal of this study has caused the need to solve a number of problems that are analyzed in the relevant parts of the work. In Section 2, there is a review of literature on the topic of research. Section 3 presents the methodological principles for assessing the capacity of the economy and its individual branches to achieve a sustainable reduction of energy consumption. Section 4 provides an empirical analysis of natural gas consumption in the Ukrainian economy and its individual branches. In Section 5, conclusions from the conducted research are drawn. Section 6 specifies limitations and prospects for further research.

2. Literature Review

The assessment of the possibilities of ensuring the energy independence of countries in terms of economic growth should be based on the study of the relationship between energy consumption and economic growth. It should be noted that there is a large number of such research works in the scientific literature, but the majority of them do not directly consider the aspects of ensuring energy independence. Thus, the results obtained by different authors are contradictory.

In particular, [13] we found that economic growth encourages energy consumption in countries that are members of the Organization for Economic Cooperation and Development (OECD), both in the short- and long-term perspective. Considering the relationship between the consumption of natural gas and the change in gross domestic product (GDP) for Gulf countries, the authors of work [14] note the existence of co-integration and the inverse relationship between these indicators. Also, the link between natural gas consumption and economic development was proven in the case of the economies of China and Japan [15]. However, [16] indicates that not all countries that are members of the Organization of the Petroleum Exporting Countries (OPEC) have such a link. In [17], for the 12 European countries, the long-term impact of natural gas consumption on economic growth has been determined, but there is a lack of such impact in the short-term perspective.

Individual researchers use other indicators of economic growth instead of GDP. In particular, [18] the Index of Sustainable Economic Welfare (ISEW) is used for this purpose. It was established that in the short term for G7 countries, this index depends on energy consumption; however, it is possible in the long-term perspective to reduce energy consumption without compromising sustainable economic welfare. We should also highlight research on the economies of individual African countries in [19], which showed that energy consumption has a relationship with stock market indicators and industrialization.

One of the important ways of reducing the consumption of natural gas and other fossil fuels is their replacement by renewable energy sources. At the same time, for many countries there is an inherent tendency to increase the share of renewable energy sources in the total energy consumption [20]. Therefore, research on the relationship between consumption of renewable energy sources and economic growth is of considerable interest. The results of these studies, performed by different scientists, vary according to the countries that were studied. Thus, the analysis of renewable energy consumption in 38 countries of the world, carried out in [21], has shown the positive effect of this consumption on economic growth only in 57% of countries. A similar study conducted for EU countries showed that

overall, the impact of renewable energy consumption on economic growth is positive, but this impact is not statistically significant for all countries [22]. We should also note the results obtained in [23], which assessed the impact of renewable energy consumption on economic growth for the Black Sea and Balkan countries. It was found that for some of these countries, including Ukraine, the investigated influence was direct, while for other countries this influence was reversed.

In general, the inconsistency in the results obtained by various authors who investigated the relationship between energy consumption and economic growth may be due to the difference in the structure and conditions of the economic functioning of the country, which is under study. Finally, this is recognized by the authors themselves in their similar studies [24], warning against unequivocally perceiving energy as a positive factor in economic development [25]. Thus, we can conclude that, at least, for some economies, economic growth is possible with a simultaneous reduction in the consumption of fossil fuels, in particular, natural gas. At the same time, such a reduction should be primarily made by increasing efficiency of the use of the appropriate types of energy.

However, the possibility of ambiguous effects of energy efficiency on energy consumption due to the existence of the so-called energy rebound effect should be borne in mind. This effect, which has been studied in detail in [26,27], tells that increasing energy efficiency can lead to a disproportionate reduction in energy consumption and, in some cases, to an increase in demand for a particular type of energy. However, not all studies devoted to this effect have revealed its action. In particular, in [28], the presence of this effect was not found. However, in [29], the authors came to the conclusion that there is a macroeconomic rebound effect in the Chinese economy. This conclusion is also confirmed by the results set out in [30], although the authors of this paper note that the rebound effect is demonstrating a downward trend. In general, it is necessary to take into account the energy rebound effect, however, in most cases, its impact on the volume of energy consumption is limited [31].

In general, the difference in the dynamics of energy efficiency can be seen as one of the factors causing differences in the ratio between economic growth and energy consumption in different countries. Moreover, the energy efficiency factor can lead to a non-linear relationship between economic growth and energy consumption. The existence of these connection was found in particular in [32], although, for example, it was not fixed in [33]. According to the authors of the paper [34], which explores the relationship between electricity consumption and economic growth in Algeria, the non-linearity of the relationship between these indicators is due to the fact that with the increase in their income consumers can afford to buy more energy-efficient devices.

Increasing energy efficiency requires improving of energy audit in both the industrial and household sectors [35], as well as accelerating implementation of energy saving technologies [36]. However, various barriers often arise on the road to such implementation [37]. The question of most significant barrier from all of them is considered in a number of scientific works. Thus, in [38], economic barriers are identified as the main obstacles to implementing of energy-efficient technologies. In [39], the main barrier to the implementation of energy-saving technologies is the lack of necessary financial incentives, while information barriers are determined as decisive in [40,41]. Also, individual researchers, in particular, the authors of work [42], indicate the impact of the size of the firm on its ability to implement measures for improving energy efficiency. In general, various authors suggest somewhat different ways of grouping obstacles to the implementation of energy-saving technologies. Herewith, the information, organizational, technical, financial, economic and institutional barriers are the most considered. However, enough attention is not always paid to the ability of energy consumers to assess the effectiveness of investing in energy-efficiency measures. At the same time, such an ability requires diverse knowledge, in particular, of the regularity of technological changes [43], diffusion of technologies mechanisms [44], the risk of their implementation [45], etc. It is important to note the role played by state policy in the field of energy consumption regulation, in overcoming the barriers to energy efficiency. In particular, this relates to the financial assistance provided for the implementation of energy-saving measures and tax privileges for those energy consumers who implement these measures [46].

Among the factors that affect the implementation of energy-saving technologies and the overall dynamics of energy consumption, it is necessary to indicate a change in prices of energy carriers [47]. In general, changes in prices of energy resources can have a significant impact on various macroeconomic indicators, in particular on GDP dynamics [48], budget revenues [49], investment activity [50], etc. The results of assessing the impact of changes in prices of energy resources on the economy differ significantly in the various studies devoted to this issue. Thus, [51] states that the rise in oil prices had a negative impact on China's economy. At the same time, it was found in [52] that such an increase positively affected the Vietnamese stock market. Eventually, in [53], the analysis of the Lithuanian economy did not reveal any significant impact of the growth of prices of energy carriers on economic development. Also the results of various researchers, obtained by them in the process of analyzing the impact of changes of prices of energy carriers on the volume of energy consumption, are contradictory. In particular, this concerns studies on the impact of changes in electricity prices on household consumption. Indeed, in [54], the absence of such an effect was established, whereas in [55] this effect was detected.

In general, the impact of rising prices of energy carriers on the economy can be considered as positive if such growth stimulates the introduction of energy saving technologies, but does not lead to a reduction in business activity. The fulfillment of this condition depends on the ways of adaptation to the growth of prices of energy carriers which dominate the economy and its industries [56]. The establishment of the regularity of the impact of rising prices of energy carriers on the volume of their consumption for those energy resources, the requirement of which is fully or partially covered by imports, is especially important. This is due to the fact that in this case, the growth of prices of energy carriers can be considered as a factor that indirectly affects reducing the dependence on imports of energy carriers.

It is important to note that the problem of reducing the dependence of economies of different countries on imports of energy resources and the achievement of energy independence is in the spotlight of many scientists. They consider the question of ensuring energy independence at the level of countries and regions [57], as well as at the level of individual energy consumers [58]. Herewith, the ways of reducing energy dependence [59] are determined, the main tasks that appear [60] are pointed out, and the experience of some countries in achieving energy independence is described [61]. At the same time, the problem of assessing the possibilities for achieving energy independence simultaneously with ensuring economic growth is not yet fully resolved. In particular, it is necessary to establish the conditions under which it is possible to achieve a sustainable reduction of energy consumption maintaining the proper rates of economic growth. It is also necessary to distinguish the apparatus of state regulation of energy consumption, which will help to achieve the desired ratio between the change in energy consumption and the rates of economic growth. This may be useful in developing a state energy strategy aimed at reducing dependence on imports of energy carriers.

3. Methodology

3.1. Modeling the Relationship between the Change in Value Added and Changes in Energy Consumption and Definition of Conditions for Energy-Saving Economic Growth at the Sectoral Level

The research of the correlation between economic growth and the change in energy consumption requires the preliminary choice of a method for evaluating relevant indicators. Regarding the volumes of energy consumption, their assessment can be made in the physical units of the corresponding energy resources or in conventional units, in particular units of oil equivalent. As for economic growth, the added value is one of the most representative indicators. This indicator, on the one hand, can be easily estimated on the basis of sectoral statistics. On the other hand, indicators of sectoral added value can be aggregated and directly determine the GDP. Given this, further in this work indicator of added value will be the measure of economic growth.

In general, for the various sectors of the economy and at different time intervals, the nature of the correlation between the change in value added and the change in the consumption of a particular

type of energy (in particular, natural gas) may be different. According to Figure 1, six types of such correlation are possible. In this case, special attention should be paid to the case where the growth of value added is accompanied by a decrease in the consumption of certain energy resources. Such a correlation between the listed indicators can be called energy-saving economic growth.

Figure 1. Types of correlation between the rates of growth of value added (α) and the rates of growth of consumption of a certain energy resource (β).

An assessment of the ability of the country's economy to sustainable volume reduction of the consumption of a particular type of energy resource needs a preliminary assessment of such ability for each sector of the economy. As follows from Figure 2, for this purpose, it is necessary for each sector to identify the type of correlation between the value added change and the volumes of consumption of a certain type of energy resources, in particular, the volume of natural gas consumption. In the process of further analysis, it is necessary to identify the reasons which caused this type of correlation for each economic sector.

Figure 2. The sequence of assessing the ability of the economy to reduce sustainably the consumption of particular type of energy resources while simultaneously ensuring economic growth.

To establish the relationship between the change in consumption of a certain type of energy resources and the change in value added, it is advisable to submit the growth rates of these indicators as follows:

$$\alpha = V_{a1}/V_{a0} - 1 = I_{Va} - 1 = I_p \cdot I_{av} - 1, \quad (1)$$

$$\beta = E_1/E_0 - 1 = I_E - 1 = I_p \cdot I_e - 1, \quad (2)$$

where α —growth rate of value added in a certain sector of economy, share of unit; V_{a1} , V_{a0} —value added, created in the investigated sector of economy, respectively, in the reporting and base periods, monetary units; I_{Va} —sectoral (industry) value added index ($I_{Va} = V_{a1}/V_{a0}$); I_p —sectoral index of physical volume of sales; I_{av} —sectoral index of value added per unit of physical output ($I_{av} = I_{Va}/I_p$); β —growth rate of consumption of particular type of energy resources in certain specific sectors of the economy, share of unit; E_1 , E_0 —volumes of consumption of particular type of energy resources in a particular sector of the economy respectively in the reporting and base periods; I_E —sectoral index of volumes of consumption of certain type of energy resources ($I_E = E_1/E_0$); I_e —sectoral index of consumption of certain type of energy resources per unit of physical volume of production ($I_e = I_E/I_p$).

Taking into account Equations (1) and (2), the relationship between the change in the consumption of a particular energy resource and the change in value added can be represented as follows:

$$(\alpha + 1)/(\beta + 1) = (I_p \cdot I_{av})/(I_p \cdot I_e) = I_{av}/I_e, \quad (3)$$

$$\alpha = (I_{av}/I_e) \cdot (\beta + 1) - 1 = I_{ef} \cdot (\beta + 1) - 1, \quad (4)$$

where I_{ef} —sectoral index of efficiency of the use of certain energy resources ($I_{ef} = I_{av}/I_e$).

Using Equations (1) and (2), it is also possible to establish conditions for energy-saving economic growth in a particular industry by certain energy resource. As already noted above, for this indicator α must be positive, and the index β must be negative. The following inequalities must be fulfilled:

$$I_p \cdot I_{av} - 1 > 0, \quad (5)$$

$$I_p \cdot I_e - 1 < 0, \quad (6)$$

or

$$1/I_{av} < I_p < 1/I_e, \quad (7)$$

Similarly, it is possible to establish the formalized conditions shown above in Figure 1 other types of ratio between the growth rate of sectoral value added and the growth rate of consumption of certain energy resources.

The corresponding conditions have the form of inequalities, which are presented in Table 1.

Table 1. Formalized conditions for the implementation of various relations between the growth rates of sectoral value added and the growth rates of consumption of certain energy resources.

Types of Relations between the Growth Rates of Sectoral Value Added and the Growth Rates of Consumption of Certain Energy Resources		Conditions of Realization of the Corresponding Relations between the Growth Rates of Sectoral Value Added and the Growth Rates of Consumption of Certain Energy Resources
I	$\alpha < 0, \beta < 0, \alpha > \beta$	$I_p < 1/I_{av} < 1/I_e$
II	$\alpha < 0, \beta < 0, \alpha < \beta$	$I_p < 1/I_e < 1/I_{av}$
III	$\alpha > 0, \beta < 0$	$1/I_{av} < I_p < 1/I_e$
IV	$\alpha > 0, \beta > 0, \alpha > \beta$	$1/I_e < 1/I_{av} < I_p$
V	$\alpha > 0, \beta > 0, \alpha < \beta$	$1/I_{av} < 1/I_e < I_p$
VI	$\alpha < 0, \beta > 0$	$1/I_e < I_p < 1/I_{av}$

Thus, in order to ensure the energy-saving economic growth by particular energy resource in a certain economic sector, it is necessary to fulfill two basic conditions:

(1) the sectoral index of value added per unit of physical volume of production should exceed the sectoral index of volumes of consumption of a certain energy resource per unit of physical volume of production. In other words, the sectoral index of the efficiency of using a particular energy resource must exceed one;

(2) the sectoral index of physical volumes of product sales should meet inequality (7).

Accordingly, it is possible to distinguish three main reasons for the fact that in a certain branch of the economy there is no energy-saving economic growth by certain energy resources:

(1) the sectoral index of efficiency of the use of a certain energy resource does not exceed one;

(2) the sectoral index of efficiency of the use of particular energy resource exceeds one; however, the sectoral index of physical volumes of sales is too low;

(3) the sectoral index of the efficiency of using a certain energy resource exceeds one, however, the sectoral index of physical volumes of sales is too high.

3.2. Method of Decomposition of Sectoral Index of Efficiency of Energy Use

A more profound analysis of the regularities of energy-saving economic growth by particular energy resource requires the identification of factors that influence the sectoral index of efficiency of the use of this energy resource. As follows from the above, the value of this index is determined by the value of sectoral indices of value added and volume of consumption of certain energy resource per unit of output. In turn, the sectoral index of value added per unit of output can be presented as follows:

$$I_{av} = \frac{I_{Va}}{I_p} = \frac{V_{a1}}{V_{a0} \cdot I_p} = \frac{R_1 - C_1}{V_{a0} \cdot I_p} = \left(\frac{R_0}{V_{a0}} \cdot \frac{R_1}{R_0} - \frac{C_0}{V_{a0}} \cdot \frac{C_1}{C_0} \right) \cdot \frac{1}{I_p}, \quad (8)$$

where R_1, R_0 —income (revenue) from sales of products by industry by minus indirect taxes, respectively, in the reporting and base periods, monetary units; C_1, C_0 —the intermediate consumption of the enterprises in this sector in the reporting and base periods, monetary units.

Equation (8) can be transformed into the following expression:

$$I_{av} = \left(\frac{R_0}{V_{a0}} \cdot I_R - \frac{R_0 - V_{a0}}{V_{a0}} \cdot I_C \right) \cdot \frac{1}{I_p} = \left(\frac{1}{l_0} \cdot I_{pr} \cdot I_p - \frac{1 - l_0}{l_0} \cdot I_c \cdot I_p \right) \cdot \frac{1}{I_p} = \frac{1}{l_0} \cdot I_{pr} - \frac{1 - l_0}{l_0} \cdot I_c \quad (9)$$

where I_R —index of income (revenue) from sales of products by economic sector by minus indirect taxes ($I_R = R_1/R_0$); I_C —index of intermediate consumption of the enterprise in the economic sector ($I_C = C_1/C_0$); l_0 —share of value added in income from products sales of enterprises of in the particular economic sector in the base period, share of unit ($l_0 = V_{a0}/R_0$); I_{pr} —sectoral price index for products ($I_{pr} = I_R/I_p$); I_c —sectoral index of intermediate consumption per unit of physical output ($I_c = I_C/I_p$).

In its turn, the sectoral index of intermediate consumption per unit of physical output can be represented by the following formula:

$$I_c = \frac{C_1}{C_0 \cdot I_p} = \frac{C_{E1} + C_{E01} + C_{o1}}{C_0 \cdot I_p} = \frac{C_{E0}}{C_0 \cdot I_p} \cdot I_{CE} + \frac{C_{E00}}{C_0 \cdot I_p} \cdot I_{CE0} + \frac{C_{o0}}{C_0 \cdot I_p} \cdot I_{Co}, \quad (10)$$

where C_{E1}, C_{E0} —expenses of enterprises of the particular economic sector for the purchase of certain energy resources, respectively, in the reporting and base periods, monetary units; C_{E01}, C_{Ej0} —expenses of enterprises of the particular economic sector for the purchase of other types of energy resources respectively in the reporting and base periods, monetary units; C_{o0}, C_{o1} —other expenses of enterprises of the particular economic sector for intermediate consumption, respectively, in the reporting and base periods, monetary units; I_{CE}, I_{CE0}, I_{Co} —sectoral indices of expenses of enterprises of the particular economic sector respectively for: purchase of certain energy resources, purchase of other energy resources and other types of intermediate consumption ($I_{CE} = C_{E1}/C_{E0}$; $I_{CE0} = C_{E01}/C_{E00}$; $I_{Co} = C_{o1}/C_{o0}$).

It should be noted that in assessing the costs of enterprises of the particular economic sector for the purchase of other types of energy resources, physical volumes of their consumption can be estimated in comparable units (in particular, in tons of oil equivalent). Under such conditions it is possible to estimate the total volume of such consumption. The index of physical volumes of consumption of other types of energy resources will be determined as the ratio of these volumes in the reporting and base periods. Given this circumstance, the Equation (10) can be presented as follows:

$$I_c = h_0 \cdot I_{ce} + g_0 \cdot I_{coe} + (1 - h_0 - g_0) \cdot I_{co} = h_0 \cdot I_{pre} \cdot I_e + g_0 \cdot I_{preo} \cdot I_{eo} + (1 - h_0 - g_0) \cdot I_{co}, \quad (11)$$

where h_0 —share of expenses for the purchase of a certain type of energy resources in the structure of intermediate consumption in the economic sector in the base period, share of unit ($h_0 = C_{EO}/C_0$); I_{ce} —sectoral index of enterprises expenses for the purchase of a certain energy resource per unit of physical volume of production ($I_{ce} = I_{CE}/I_p$); g_0 —share of expenses for the purchase of other types of energy resources in the structure of intermediate consumption in the economic sector in the base period, share of unit ($g_0 = C_{EOO}/C_0$); I_{coe} —sectoral index of expenses of enterprises of the particular economic sector for purchasing other energy resources per unit of output ($I_{coe} = I_{COE}/I_p$); I_{co} —sectoral index of other types of intermediate consumption per unit of output ($I_{co} = I_{CO}/I_p$); I_{pre} —sectoral price index for a certain type of energy resources ($I_{pre} = I_{CE}/I_p$); I_{eo} —sectoral index of physical volumes of consumption of other types of energy resources; I_{preo} —sectoral price index for other types of energy resource ($I_{preo} = I_{CEO}/(I_p I_{eo})$).

Taking into account Equations (1), (2), (4), (8)–(11) it is possible to construct a model of the influence of factors on the change in value added and in volumes of consumption of a particular type of energy resources in the economic sector.

This model is schematically presented in Figure 3. The designations in the model correspond to designations in the formulas presented above. The deterministic relationships between the indicators directly derived from these formulas are represented by solid arrows in Figure 4. At the same time, the dashed arrows in Figure 3 depict the statistical relationships that, under certain conditions, may arise between individual indicators.

Figure 3. Model of influence of factors on the change in value added and change in consumption of certain energy resources in the industry. *Note:* the designation of the presented indicators corresponds to the designation of the indicators in the Equations (1), (2), (4), (8)–(11).

Figure 4. Model of decomposition of the growth rate of the sectoral level of efficiency of the use of a particular type of energy resources. *Note:* the designation of the indicators presented in Figure 5 corresponds to the designation of the indicators in the Equations (9)–(11).

Figure 5. Model of influence of energy prices on consumption of a certain type of energy resources and on other indicators of activity of enterprises of the economic sector.

On the basis of Equations (9)–(11) it is possible to estimate the influence of individual factors on the value of the sectoral index of energy efficiency. To this end, it is expedient to realize the decomposition of the growth rate of the level of energy use efficiency in the reporting period compared to the base period. In particular, this growth rate can be presented as follows:

$$\Delta I_{ef} = I_{ef} - 1 = I_{av}/I_e - 1 = I_{av} - 1 + 1/I_e - 1 + (I_{av} - 1) \cdot (1/I_e - 1) = \Delta I_{ef1} + \Delta I_{ef2} + \Delta I_{ef3} \quad (12)$$

where ΔI_{ef} —growth rate of the sectoral level of the efficiency of the use of a particular type of energy resources, share of unit; ΔI_{ef1} —part of the increase in the level of efficiency of the use of a particular type of energy resources due to the change in value added per unit of output ($\Delta I_{ef1} = I_{av} - 1$); ΔI_{ef2} —part of the increase in the level of efficiency of the use of a particular type of energy resources, due to the change in the volume of consumption of this energy resource per unit of output ($\Delta I_{ef2} = 1/I_e - 1$); ΔI_{ef3} —part of the increase in the level of efficiency of the use of a particular type of energy resources, due to the joint influence of both of these factors ($\Delta I_{ef3} = (I_{av} - 1)(1/I_e - 1)$).

Using Equations (9)–(11), in a similar way, we can realize the decomposition of the growth rate of the sectoral value added index per unit of physical output. The results of decomposition are shown in Figure 4. From this figure it follows, in particular, that the change in the consumption of certain energy resource per unit of physical output produces a double effect on the change in the efficiency of the use of a particular type of energy resources. Firstly, this effect occurs directly, as follows from Equation (12). Secondly, this effect is realized through a change in the value added per unit of physical output.

3.3. Modeling the Effect of Energy Price Increases on Energy Consumption and Sectoral Value Added

Achieving the energy-saving economic growth of the economic sector requires a reduction in the consumption of certain energy resource per unit of physical volume of production. However, various barriers may arise along the way to such implementation, among which, in particular, we should identify the economic barriers. For assessing the economic efficiency of investments in the implementation of energy-saving technologies at the level of a separate product type, we should distinguish two main conditions in which such an introduction is expedient for the investor:

(1) replacement of existing technology with energy-saving technology should provide for a company that plans to implement this technology a sufficiently large profit increase. Failure to fulfill this condition will be called the economic barrier of the first kind;

(2) the company must have sufficient financial resources to implement energy-saving technology. In particular, if financing of such implementation is carried by a bank loan, the enterprise should receive a sufficiently large cash flow in order to repay the borrowed sum in a timely manner. Failure to fulfill this condition will be called the economic barrier of the second kind.

The modeling of these barriers to the implementation of energy-saving technologies is presented in Appendix A. According to the models below, the change in prices for the energy resource whose consumption is supposed to be reduced as a result of the implementation of energy-saving technology has a direct impact on the level of economic barriers on the way to such implementation. At the same time, this impact is ambiguous. On the one hand, the rising energy prices weaken the economic barrier of the first type. However, on the other hand, the rising energy prices may increase the economic barrier of the second type. This is due to the fact that the increase in energy prices leads to an increase in the cost of the enterprise and, accordingly, causes a decrease in the flow of cash proceeds to repay the loan taken to finance the implementation of energy-saving technology. It follows from this that there is a certain range of energy prices, in which the indicator of a generalized assessment of economic barriers to the implementation of energy-saving technology is the smallest.

It is important to note that the rise in energy prices may not only increase energy efficiency but also lead to a reduction in energy consumption due to a decrease in physical volumes of production. Such a reduction will occur if companies will adapt to the increase in energy prices by increasing the prices for their products. This situation, in its turn, leads to a reduction in the physical volumes of production and sales of the company.

Consequently, the rise of energy prices can affect their consumption both through increased energy efficiency and as a result of lower physical volumes of production, as shown in Figure 5.

At the same time, the growth rate of consumption of certain energy resources can be represented as follows:

$$\Delta I_E = I_E - 1 = I_p \cdot I_e - 1 = I_p - 1 + I_e + (I_p - 1) \cdot (I_e - 1) = \Delta I_{E1} + \Delta I_{E2} + \Delta I_{E3}, \quad (13)$$

where ΔI_E —the growth rate of the sectoral volume of consumption of a certain energy resource, share of unit; ΔI_{E1} —part of the growth of the sectoral volume of consumption of certain energy resource, due to changes in the physical volume of production ($\Delta I_{E1} = I_p - 1$); ΔI_{E2} —part of the growth of the sectoral volume of consumption of a certain energy resource due to changes in the volume of consumption of this energy resource per unit of physical volume of production ($\Delta I_{E2} = I_e - 1$); ΔI_{E3} —part of the growth of the sectoral consumption of certain energy resources, due to the joint influence of both of these factors ($\Delta I_{E3} = (I_p - 1)(I_e - 1)$).

The change in total operating costs of the industry due to such growth is one of the main factors influencing the choice of ways of adapting the economic sectors to increasing prices for a certain energy resource. This change in relative terms can be estimated by the following formula:

$$\Delta C_{op} = (C_{E0} \cdot I_{pr} \cdot I_e - C_{E0}) / C_{op0} = s_0 \cdot (I_{pr} \cdot I_e - 1) \quad (14)$$

where ΔC_{op} —relative change in total operating costs of enterprises of the economic sector due to rising prices for a certain energy resource, share of unit; C_{op0} —value of operating expenses of enterprises of the economic sector in the base period (before the increase of energy prices); s_0 —share of cost of purchasing energy resources in total operating expenses of enterprises of the economic sector in the base period, share of unit ($s_0 = C_{E0}/C_{op0}$).

It can be assumed that the indicator s_0 significantly influences both the choice of the way of adaptation of enterprises to the growth of energy prices, and the change in the volume of consumption of this energy and sectoral added value. Indeed, if the value of s_0 in the industry is small, then this value may remain relatively small even after increasing energy prices. Therefore, in this case, the aforementioned barrier of the first kind may appear on the way to the implementation of energy-saving technologies in the industry. On the other hand, if the value of s_0 in the industry is high, then, after increasing energy prices, the profitability of enterprises in the industry can be significantly reduced. This, in turn, will result in the emergence of a barrier of the second kind to the implementation of energy-saving technologies in the industry. It is clear that the possible appearance in a particular industry of this or that barrier will depend on how much energy prices increase: the higher the growth, the lower the barrier of the first kind, but the barrier of the second kind increases. In view of the above, the following hypothesis can be formulated:

Hypothesis 1. *The growth of energy prices leads to the most vivid increase in the efficiency of its use, mainly in industries with an average share of the cost of purchasing this energy resource in total operating costs.*

Taking into account Equation (14), hypothesis 1 can be strengthened by formulating the following assumption:

Hypothesis 2. *The lowest relative growth of operating costs due to the increase in energy prices is inherent in sectors with a small and average share of the cost of purchasing this energy in total operating costs.*

If hypothesis 2 is fair, we can expect that the rise in energy prices will not significantly affect its consumption and the value added change in industries with a small share of the cost of purchasing this energy in total operating costs. At the same time, industries with an average value of the share of energy purchase costs in total operating costs can provide a reduction in the consumption of this energy simultaneously increasing the sector value added. Given this, one can formulate the following hypothesis:

Hypothesis 3. *The growth of energy prices may lead to energy-saving economic growth, mainly in industries with an average value of the share of the energy purchase costs.*

3.4. Modeling the Relationship between Change in Energy Consumption, Added Value and Energy Dependence at the Macro Level

Establishing the relationship between the change in energy consumption and the change in added value is possible not only at the level of individual branches of the economy, but also at the macro level. In this case, macro level will be understood as the aggregate of industries or the whole economy of the country as a whole. In the latter case, the value added will be transformed into GDP, and it is also advisable to consider the level of energy dependence of the country on a given energy resource.

During the research of energy consumption at the level of the totality of industries, it is necessary to take into account the factor of structural shifts. This can be done using the decomposition model of the change in the consumption of certain energy resources presented in Appendix B.

It is also important to distinguish commercial and non-commercial energy consumers. The second category of consumers, in particular, includes the residential sector and government agencies. Changing the volume of consumption of imported energy does not significantly affect the country's GDP. Consequently, the reduction of such consumption can be considered as one of the main directions of providing macroeconomic energy-saving growth.

In addition to reducing energy consumption, an important condition for reducing the energy dependence of a country is the increase of its own production of the corresponding type of energy resources. Therefore, it is necessary to simulate the combined effect of these two directions of reducing energy dependence on the level of such dependence. It should be borne in mind that the level of energy dependence of the country by a certain energy resource can be estimated in two ways:

(1) by the absolute value of the demand for imported energy supplies (i.e., as the difference between its consumption and its own production). The condition for reducing this need in the reporting period compared with the base period can be presented in the form of such inequality:

$$E_{cc0} \cdot I_{gp} \cdot I_{egp} + E_{nc0} \cdot I_{Enc} - M_0 \cdot I_M < E_{cc0} + E_{nc0} - M_0, \quad (15)$$

or

$$I_{gp} < \frac{1 + \frac{M_0}{E_{cc0} + E_{nc0}} \cdot (I_M - 1) - v_0 \cdot I_{Enc}}{(1 - v_0) \cdot I_{epg}}, \quad (16)$$

(2) as a share of the need for external energy resources in the total volume of its consumption. The condition for reducing this share in the reporting period compared to the base period can be presented in the form of such inequality:

$$\frac{E_{cc0} \cdot I_{gp} \cdot I_{egp} + E_{nc0} \cdot I_{Enc} - M_0 \cdot I_M}{E_{cc0} \cdot I_{gp} \cdot I_{egp} + E_{nc0} \cdot I_{Enc}} < \frac{E_{cc0} + E_{nc0} - M_0}{E_{cc0} + E_{nc0}}, \quad (17)$$

or

$$I_{gp} < \frac{I_M - v_0 \cdot I_{Enc}}{(1 - v_0) \cdot I_{epg}}, \quad (18)$$

where E_{cc0} —total physical volumes of consumption of certain energy resources by all commercial consumers in the base period; I_{gp} —country's GDP index; I_{egp} —the index of the ratio between the volumes of consumption of certain energy by all commercial consumers and the value of GDP; E_{nc0} —total physical volumes of consumption of certain energy resources by all non-commercial consumers in the base period; I_{Enc} —index of aggregate physical volumes of consumption of certain energy resources by all non-commercial consumers; M_0 —volumes of own extraction of certain energy resources; I_M —index of volumes of own extraction of certain energy resources; v_0 —the share of non-commercial consumption of a certain energy in the total volume of its consumption in the base period, share of unit.

Thus, a decrease in the country's energy dependence on imports of certain energy resources while simultaneously increasing GDP will be achieved in condition if the GDP index exceeds the 1, but is lower than its maximum values. These values are given by the right sides of the Equations (16) and

(18). In this case, if in the base period the economy of the country was dependent on imports (means that $M_0 < E_{cc0} + E_{nc0}$), the value of the right-hand side of the Equation (18) is always less than the value of the right-hand side of the Equation (16). Therefore, the decrease in the relative level of energy dependence imposes less stringent requirements on the value of the GDP index, rather than reducing the energy dependence on the absolute value of the demand for imported energy supplies.

Equating the left side of the Equation (17) to zero, we can determine the maximum possible value of the GDP index, which will achieve full energy independence from the import of a particular energy resource:

$$I_{gpmax} = \frac{\frac{M_0}{E_{cc0} + E_{nc0}} \cdot (I_M - 1) - v_0 \cdot I_{Enc}}{(1 - v_0) \cdot I_{epg}}, \quad (19)$$

where I_{gpmax} —the maximum possible value of the GDP index, which will achieve full energy independence from the import of a particular energy resource.

The above Equations (15)–(19) can be used in assessing the potential of reducing the energy dependence of countries on imports of certain energy resources.

4. Empirical Analysis

4.1. Estimation of Natural Gas Consumption in the Economy of Ukraine in Comparison with Other Countries

Despite the fact that in recent years, in many countries of the world, the volume of consumption of energy from renewable sources is increasing [62], natural gas remains one of the most important energy sources. The trend of changes in natural gas consumption varies considerably between countries. The deeper patterns of these changes can be established by estimating the ratio between real GDP and natural gas consumption by countries. As follows from the data presented in Table S1 (Supplementary), the magnitude of this ratio for 2010–2017 in different countries varied in different ways. In particular, the ratio between real GDP and natural gas consumption during this period increased most strongly in Finland (by 140.83%), in the United Kingdom (by 43.64%), in the Netherlands (by 37.82%), in Romania (by 36.71%) and Hungary (by 35.12%) [63,64]. At the same time, the growth rate of the ratio between real GDP and natural gas consumption was much smaller in countries such as Turkey (8.19%), Poland (6.34%) and the USA (1.43%). In China and Australia, the ratio between real GDP and consumption of natural gas in general has decreased.

One of the reasons that may cause different dynamics of the ratio between real GDP and natural gas consumption in different countries is the differences in their economic structure. Differences in the trend in the correlation between added value and natural gas consumption in different sectors of the economy of the analyzed countries are also important. A more detailed research of these trends will be made for Ukraine. This case is of interest, in particular, because in recent years Ukraine has experienced a sharp decline in natural gas consumption. In particular, as follows from the data in Table 2, the total consumption of natural gas in the economy of Ukraine has decreased from 66.1 billion cubic meters in 2010 to 29.8 billion cubic meters in 2017, i.e., where was a fall of more than two times. If we will compare the volume of natural gas consumption in Ukraine in 2017 from 2010, the reduction of these volumes was 45.42%. It should be noted that in none of the countries discussed above in Table 2, except for Finland, the percentage of natural gas consumption reduction was not so high. It should also be noted that at some time intervals (for example, if compared with 2013 with 2009), Ukraine's real GDP growth was accompanied by a reduction in natural gas consumption.

Table 2. Indicators of the correlation between real GDP and natural gas consumption in Ukraine for 2007–2017¹.

Years	Real GDP (at Constant Prices in 2010)		Total Natural Gas Consumption		The Ratio of Real GDP to the Volume of Natural Gas Consumption		Share of Natural Gas Consumption in Total Energy Consumption %
	Billion USD	Growth Rate Relative to 2007, times	Billion Cubic Meters	Growth Rate Relative to 2007, times	USD per 1 Cubic Meter of Gas	Growth Rate Relative to 2007, times	
2007	395.2	1.0	69.8	1.0	5.66	1.0	69.8
2008	404.3	1.02	66.3	0.95	6.10	1.08	66.3
2009	344.5	0.87	51.9	0.74	6.64	1.17	51.9
2010	358.9	0.91	57.6	0.83	6.23	1.10	57.6
2011	378.5	0.96	59.3	0.85	6.38	1.13	59.3
2012	379.4	0.96	54.8	0.79	6.92	1.22	54.8
2013	379.3	0.96	50.4	0.72	7.53	1.33	50.4
2014	354.5	0.90	42.6	0.61	8.32	1.47	42.6
2015	319.8	0.81	33.8	0.48	9.46	1.67	33.8
2016	327.2	0.83	32.0	0.46	10.23	1.81	32.0
2017	335.4	0.85	31.5	0.45	10.65	1.88	31.5

¹ Sources of input information: [65,66]

A significant decrease in natural gas consumption in Ukraine during 2007–2017 was due to various reasons. In particular, decrease in the value of real GDP has some impact. However, this influence was not decisive, as the reduction of natural gas consumption in Ukraine during the period under research was accompanied by a significant increase in the ratio of real GDP to natural gas consumption (from 5.66 USD per one cubic meter of gas in 2007 to 10.65 USD per one cubic meter of gas in 2017). Such an increase in the ratio between the real GDP of Ukraine and the volume of natural gas consumption was greatly stimulated by a significant increase in natural gas prices for commercial consumers (approximately 11 times in the national currency [65]). In turn, such a rise in prices was caused by an increase in import prices for natural gas, and a gradual decrease of state subsidies of its consumers. However, despite the significant increase in the ratio of real GDP to natural gas consumption in the Ukrainian economy, the magnitude of this ratio in 2017 was less than in other countries. These data are presented in Table S1 (Supplementary). This may indicate significant reserves further reduction of natural gas consumption in the Ukrainian economy.

4.2. Analysis of Natural Gas Consumption in the Industry of Ukraine and its Individual Sectors

The industry is one of the largest consumers of natural gas in Ukraine. It should be noted that in 2017 compared to 2007, the total volume of natural gas consumption in the Ukrainian industry decreased by approximately 4 times [65]. However, as can be seen from the data presented in Table 3, in some years of the studied period, the consumption of natural gas in the Ukrainian industry increased in comparison with the previous years. Using Equation (13), we realized the decomposition of the growth rate of natural gas consumption by Ukrainian industry for 2008–2017 (Table S2, Supplementary). As the result of this decomposition, the change in the volume of natural gas consumption per unit of physical output was the main factor that caused the change in the volumes of natural gas used in Ukrainian industry in most of the years. It should be noted that the industries of Ukraine, which are the biggest consumers of natural gas, are the following: ferrous metallurgy, production of non-metallic mineral products, mining industry, food and tobacco industry, as well as chemical and petrochemical industry. The dynamics of natural gas consumption by the listed industries of Ukraine is shown in Figure 6. From this figure, we can see that for all listed industry sectors of Ukraine, in the majority of years, there was a decrease in natural gas consumption.

Table 3. Growth rates of the sectoral volume of natural gas consumption (relative to the previous year) due to changes in consumption of this energy per unit of physical volume of production by industries of Ukraine, share of unit ¹.

Industry Sectors	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Ferrous metallurgy	0.005	−0.131	0.092	−0.080	−0.210	−0.171	−0.109	−0.053	−0.237	0.094
Chemical and petrochemical industry	−0.093	−0.287	−0.133	0.205	−0.092	−0.113	−0.299	0.018	0.343	−0.322
Color metallurgy	0.195	−0.031	0.071	−0.089	−0.334	0.598	−0.201	0.166	−0.101	0.058
Production of non-metallic mineral products	−0.011	−0.564	−0.147	−0.002	−0.197	−0.108	−0.085	−0.053	−0.055	−0.082
Production of transport equipment	−0.243	0.247	−0.191	−0.006	1.035	−0.221	−0.506	−0.346	0.016	0.418
Machine building	−0.053	−0.191	0.021	0.041	−0.028	0.005	−0.070	−0.017	−0.168	0.180
Mining industry	−0.083	−0.040	0.107	−0.130	−0.128	−0.015	0.071	0.112	−0.019	−0.075
Food and tobacco industry	0.035	−0.033	−0.139	0.087	0.012	−0.004	−0.224	−0.103	−0.118	−0.085
Pulp and paper and printing industry	−0.001	−0.048	0.013	0.049	−0.046	−0.122	−0.028	−0.012	0.006	−0.013
Woodworking industry	−0.180	−0.367	0.086	−0.161	−0.167	−0.112	−0.200	−0.141	−0.762	−0.063
Construction	−0.013	0.144	0.222	−0.202	−0.034	−0.383	−0.187	1.591	−0.659	−0.223
Textile and leather industry	0.267	0.181	−0.145	0.356	−0.048	−0.204	−0.155	−0.348	0.631	0.152
Other industry sectors	0.005	−0.131	0.092	−0.080	−0.210	−0.171	−0.109	−0.053	−0.237	0.094

¹ Sources of input information: [65,66]

Figure 6. Indices of natural gas consumption in 2007 (times) by industry sectors of Ukraine, where 1—ferrous metallurgy, 2—production of nonmetallic mineral products, 3—mining industry, 4—food and tobacco industry, 5—chemical and petrochemical industry. Sources of input information: [65,66].

Table 3 shows the growth rates of the sectoral volume of natural gas consumption due to changes in the consumption of this energy per unit of physical volume of production by industry sectors of Ukraine (index ΔI_{ef2} in Equation (12)).

The overwhelming majority of the values of indicators in Table 3 are negative. This means that for most industries in Ukraine, the use of natural gas has increased in most years. At the same time, in this case, the dynamics of the efficiency of the use of natural gas was estimated by the change in consumption of this energy per unit of physical output.

At the same time, in 2017, the efficiency of natural gas consumption decreased by some industries. In particular, it concerns ferrous metallurgy, machine building and some other industries. Such a trend may indicate some exhaustion of reserves for improving the increasing the efficiency of natural gas use in certain industries in Ukraine.

The question how strong was the increase in the efficiency of natural gas use on the overall decrease in its consumption in various industries of Ukraine is also an important question.

As it follows from the data presented in Table S3 (Supplementary), for most industries this influence was rather high during 2007–2017. This influence was the largest in the wood processing industry (94.65%), in the production of non-metallic mineral products (81.7%), as well as in the chemical and petrochemical industry (72.31%). Consequently, some industries during 2007–2017 significantly reduced natural gas consumption mainly due to increased efficiency of its use.

4.3. Estimation of the Correlation between the Value Added Change and the Change in the Volume of Natural Gas Consumption in the Industrial Sectors of Ukraine

It is also possible to assess the dynamics of the natural gas use efficiency by the ratio between the change in added value of the industries and the change in volume of natural gas consumption. Such a correlation can be characterized by an index of natural gas efficiency based on the real added value. This index is calculated by dividing the real added value index by the natural gas consumption index. As follows from the data presented in Table S4 (Supplementary), the value of the index of natural gas use efficiency in terms of real added value across the entire Ukrainian industry during 2008–2017 significantly differed over the years of the investigated period. However, in most of the years, this index exceeded one, which indicates a general tendency to increase the efficiency of natural gas use in Ukrainian industry.

Regarding certain industries of Ukraine, according to the data of Table S5 (Supplementary), the index of efficiency of natural gas usage by the indicator of real added value significantly differed. At the same time there is a tendency to decrease the value of this index for most industries of Ukraine.

As can be seen from Figure 7, the indicators of real added value changes and volumes of natural gas consumption by different industry sectors of Ukraine fall into different zones according to the numbering of these zones, presented in Table 1 above. In particular, energy-saving economic growth was observed in some industries, but in others there was no such growth. The reasons for these differences are presented in Table 4.

Figure 7. Indicators of the ratio between the growth rates of real added value (α) and natural gas consumption (β) in the industrial sectors of Ukraine (numbering of the dots corresponds to the numbering of the sectors in Table 3): (a) in 2012 compared to 2008; (b) in 2016 compared to 2012.

Table 4. Grouping of Ukrainian industry sectors by the ratio between the change in real added value and the change in the volume of natural gas consumption.

Names of Groups of Industries	Industry Sectors that Fall into Their Respective Groups	
	When Comparing the Indicators of 2012 with 2008 Indicators	When Comparing the Indicators of 2016 with the Indicators for 2012
1. Industries in which energy saving economic growth took place	Chemical and petrochemical industry; color metallurgy; mining industry; food and tobacco industry	Color metallurgy; production of non-metallic mineral products; pulp and paper and printing industry; woodworking industry; textile and leather industry
2. Industries in which the index of efficiency of use of natural gas does not exceed one	Production of transport equipment; textile and leather industry	Mining industry
3. Industries in which the index of efficiency of natural gas use exceeded one; however, energy-saving economic growth did not occur:		
3.1. Due to the industry index of physical volumes of product sales being too low	Ferrous metallurgy; production of non-metallic mineral products; machine building; pulp and paper and printing industry; woodworking industry; construction	Ferrous metallurgy; chemical and petrochemical industry; production of transport equipment; machine building; food and tobacco industry; construction
3.2. Due to the industry index of physical volumes of product sales being too high	—	—

Taking into account that the indexes of natural gas usage efficiency to the indicator of real added value differ significantly in different industries of Ukraine, it is advisable to find out the reasons for such differences. For this purpose, the decomposition of the growth rate of the industrial level of the efficiency of the use of a certain energy resource is presented in Figure 4 above. The results of this model for the period 2012–2016 are presented in Table 5. As follows from the results presented in Table 5, for all the Ukrainian industries examined, the values of indicators ΔI_{av3} and ΔI_{av6} are negative, that means that the change in prices for natural gas and other types of energy has negatively affected the growth of the sectoral level of efficiency of natural gas use. This is due to the growth of these prices in the studied periods of time. At the same time, the value of ΔI_{av4} for most industries is positive. This is due to a decline in most sectors of natural gas consumption per unit of physical output. At the same time, looking on the data indicated in the last column of Table 5, the level of influence of such a decrease on the growth of the sectoral level of efficiency of use of natural gas significantly differed for different industries of Ukraine. In those sectors where economic growth was maintained by energy-saving measures for natural gas, this impact was the greatest.

Table 5. Results of decomposition of the growth rate of the sectoral level of the efficiency of natural gas use by industries of Ukraine in 2016 compared to 2012 ^{1,2}.

Industry Sectors	ΔI_{ef}	ΔI_{ef1}								ΔI_{ef2}	ΔI_{ef3}	$(\Delta I_{av4} + \Delta I_{ef2})/\Delta I_{ef}$
		ΔI_{av1}	ΔI_{av2}									
			ΔI_{av3}	ΔI_{av4}	ΔI_{av5}	ΔI_{av6}	ΔI_{av7}	ΔI_{av8}	ΔI_{av9}			
Ferrous metallurgy	1.39	0.29	−0.12	0.72	0.05	−0.02	0.33	0.00	−0.34	0.88	0.24	1.15
Chemical and petrochemical industry	0.26	0.42	−0.17	0.28	0.03	−0.02	0.18	0.00	−0.67	0.18	0.01	1.74
Color metallurgy	0.08	0.27	−0.10	−0.50	−0.04	−0.01	0.01	0.00	0.18	−0.25	−0.11	−8.95
Production of non-metallic mineral products	0.64	0.31	−0.08	0.38	0.02	−0.01	0.28	0.00	−0.32	0.37	0.07	1.17
Production of transport equipment	2.72	0.16	−0.03	0.56	0.02	−0.01	0.08	0.00	−0.34	2.91	−0.13	1.28
Machine building	0.16	0.02	−0.02	0.15	0.00	−0.01	0.06	0.00	−0.20	0.31	−0.04	2.94
Mining industry	−0.08	0.03	−0.08	−0.25	−0.01	−0.01	0.07	0.00	−0.12	−0.13	−0.01	5.03
Food and tobacco industry	0.39	0.03	−0.02	0.27	0.01	−0.01	0.09	0.00	−0.26	0.63	−0.10	2.36
Pulp and paper and printing industry	0.69	0.39	−0.03	0.11	0.00	−0.01	−0.07	0.00	−0.05	0.18	0.08	0.43
Woodworking industry	8.00	0.27	−0.02	0.57	0.02	−0.01	−0.16	0.00	−0.10	5.90	1.80	0.81
Construction	0.85	0.02	−0.03	0.61	0.02	−0.01	−0.07	0.00	−0.34	1.26	−0.23	2.19
Textile and leather industry	0.66	0.16	−0.02	0.22	0.01	−0.01	0.08	0.00	−0.04	0.40	0.08	0.93

¹ Sources of input information: [65,67]. ² The designation of indicators in the table corresponds to the designation of these indicators in the above Figure 4.

Consequently, we can conclude that Ukrainian examined industries due to the increase in prices for natural gas, show an increase in the efficiency of its use. In order to analyze the patterns of such an increase in more detail, we will consider the impact on it of the share of costs for the purchase of natural gas in the amount of operating costs by industries of Ukraine. As follows from the data presented in Table S6 (Supplementary), this share is quite different in different industries. We will now divide the industries of Ukraine by each of the indicators listed in Table S6 into three groups, namely: industries with small, medium and large values of the corresponding indicator. The criteria for such a gradation are presented in Table 6, and its results are presented in Table 7.

Table 6. Criteria for graduation of industries of Ukraine by separate indicators related to consumption of natural gas.

Industry Sectors Groups	Value of Indicators in which the Industry Sectors Belong to Their Respective Group		
	Share Cost of Purchasing Natural Gas in Total Operating Expenses in 2012, %	Index of Natural Gas Consumption per Unit of Physical Output in 2016 Relative to 2012, times	Relative Growth of Operating Expenses as a Result of Increase in Prices for Natural Gas in 2016 Relative to 2012, %
With low values of indicators	Less than 5%	Less than 0.6	Less than 4%
With average values of indicators	From 5% to 10%	From 0.6 to 0.8	From 4% to 8%
With high values of indicators	More than 10%	More than 0.8	More than 8%

Table 7. Division of industries of Ukraine by separate indicators related to consumption of natural gas.

Industry Sectors Groups	Value of Indicators in which the Industry Sectors Belong to Their Respective Group		
	Share Cost of Purchasing Natural Gas in Total Operating Expenses in 2012, %	Index of Natural Gas Consumption per Unit of Physical Output in 2016 Relative to 2012, times	Relative Growth of Operating Expenses as a Result of Increase in Prices for Natural Gas in 2016 Relative to 2012, %
With low values of indicators	Construction	Ferrous metallurgy; color metallurgy; production of non-metallic mineral products; pulp and paper and printing industry; textile and leather industry	Color metallurgy; production of non-metallic mineral products; machine-building; pulp and paper and printing industry; woodworking industry; construction; textile and leather industry
With average values of indicators	Production of non-metallic mineral products; pulp and paper and printing industry; woodworking industry; textile and leather industry	Production of transport equipment; machine-building; food and tobacco industry; woodworking industry	Production of transport equipment; mining industry; food and tobacco industry
With high values of indicators	Color metallurgy; ferrous metallurgy; chemical and petrochemical industry; production of transport equipment; machine-building; mining industry; food and tobacco industry	Chemical and petrochemical industry; mining industry; construction	Ferrous metallurgy; chemical and petrochemical industry

Analyzing the data presented in Table 7, we can make some conclusions. Firstly, the majority of industry sectors in which the index of natural gas consumption per unit of physical output is low, are characterized by average values of the share of expenses for the purchase of this energy resource in the total operating expenses. Secondly, most industries with low relative growth of operating costs due to the increase in natural gas prices are characterized by low or average value of the share of the cost of purchasing this energy resource in the total operating expenses. Thirdly, energy-saving economic growth by natural gas happened predominantly in sectors with an average share of the cost of purchasing this energy in the volume of operating expenses. Consequently, it can be argued that all three hypotheses, as outlined above in Section 3.3, are fulfilled for the economic sectors in Ukraine.

A more complete justification of the hypotheses expressed in Section 3.3 requires the division of the studied industry sectors into sub-sectors. As a result of this division, 50 sub-sectors of the Ukrainian industry were identified (Table S7, Supplementary). Separate data on the performance of

these sub-sectors is graphically presented in Figure 8, and the variation and correlation between these data is estimated in Table 8.

Figure 8. Graphical representation of the relation between share cost of purchasing natural gas in total operating expenses in 2012 (s_0) and other indicators of activity of industry sub-sectors of Ukraine, namely: (a) natural gas consumption index per unit of physical output in 2016 relative to 2012 (I_e); (b) a relative increase in operating costs as a result of an increase in natural gas prices in 2016 relative to 2012 (ΔC_{op}); (c) value added index (I_{Va}); (d) index of volumes of consumption of natural gas (I_E).

Table 8. Variations of values of the studied indicators and correlation coefficients between them.

Indicators ¹	Means	Min	Max	Variance	SD ²	K-S ³	The level of Correlation Between Indicators				
							s_0	I_e	ΔC_{op}	I_{Va}	I_E
s_0	9.036	2.600	14.200	12.355	3.512	0.15	1.00	0.33	0.77	−0.36	−0.02
I_e	0.682	0.408	1.179	0.030	0.174	0.17	0.33	1.00	0.28	−0.55	0.10
ΔC_{op}	4.468	1.200	9.600	5.722	2.392	0.16	0.77	0.28	1.00	−0.22	−0.10
I_{Va}	0.847	0.288	1.608	0.095	0.291	0.10	−0.36	−0.55	−0.22	1.00	0.35
I_E	0.530	0.079	1.087	0.070	0.264	0.06	−0.02	0.10	−0.10	0.35	1.00

¹ Designation of indicators: s_0 —share cost of purchasing natural gas in total operating expenses in 2012,%; I_e —index of natural gas consumption per unit of physical output in 2016 relative to 2012, times; ΔC_{op} —relative growth of operating expenses as a result of increase in prices for natural gas in 2016 relative to 2012,%; I_{Va} —sectoral (industry) value added index in 2016 relative to 2012, times; I_E —sectoral index of volumes of consumption of natural gas, times. ² SD—standard deviation. ³ K-S—Kolmogorov–Smirnov test (showed that by all indicators the set of values corresponds to the normal law of distribution).

According to the data presented in Table 8, the studied indicators show a significant level of fluctuation of their values. This level is especially high for s_0 , which ranges from 2% to 14.2%. Regarding the level of correlation between the studied indicators, according to Table 8, the most significant are the relationships between the indicators s_0 and ΔC_{op} , as well as between I_e and I_{Va} . Therefore, it can be argued that the share of costs for the purchase of natural gas in the amount of operating costs of Ukrainian industries shows a positive correlation with the increase in operating costs due to the increase in natural gas prices. At the same time, the index of natural gas consumption per unit of physical output of Ukrainian industries shows a negative correlation with the value added index.

In this case, the hypotheses expressed in Section 3.3 are confirmed by the following conclusions for the studied industry sub-sectors of Ukraine (Table S8, Supplementary):

- (1) the low value of the index I_e is inherent in 19 sub-sectors. Of these, 15 sub-sectors (i.e., 78.9%) are characterized by average values of s_0 ;
- (2) the low value of ΔC_{op} , is characteristic of 27 sub-sectors. Of these, 24 sub-sectors (i.e., 88.8%) are characterized by low or average values of s_0 ;
- (3) energy-saving economic growth in natural gas occurred in 15 sub-sectors. Of these, 13 sub-sectors (i.e., 86.7%) are characterized by average values of s_0 .

As can be seen from the locations of the points in some of the graphs in Figure 8 above, some relationships between the studied indicators may be characterized by dependencies that look like $\beta_0 + \beta_1 \cdot I + \beta_2 \cdot I^2$, where I —certain variable indicator. In particular, the indicators s_0 and I_e described above in Table 8 can act as such variables. Regarding the dependent variables of the regression equations, they can be represented by all the indicators described in Table 8 except s_0 .

It is important to note that all indicators that will be used in the regression equations are determined by comparing the data for 2016 with the corresponding data for 2012. Therefore, medium-term indexes are being considered. This is due to several circumstances.

Firstly, in 2011–2013 in Ukraine there was a significant increase in natural gas prices for industry, but in 2015–2016 the increase in natural gas prices in UAH (national currency of Ukraine) was much smaller (due to the sharp fall in crude oil prices in the world market in the second half of 2014). Therefore, in 2015–2016 Ukraine's industrial enterprises could adapt to the increase in natural gas prices, which occurred in previous years.

Secondly, there may be a large enough gap between the moment when natural gas prices rise and the moment of introduction of energy-saving technological changes, if these changes represent the response of enterprises to the increase in natural gas prices.

Third, the rise in natural gas prices in the short term cannot be considered as a factor that drives production growth. Therefore, it will take some time for industrial sectors and individual businesses to transition to energy-saving economic growth, during which positive changes will occur, in particular demand for products will increase.

Fourth, in the case of the Ukrainian economy, it is quite difficult to use in the regression dependencies the indices obtained by consistent annual values of the corresponding indicators. This is due to the fact that these values fluctuate greatly over the years as a result of political events that have taken place in Ukraine since 2014.

The results of the regression analysis of the relationship between the individual indicators of the activity of the industry sub-sectors of Ukraine are presented in Table 9. The total number of observations for each indicator corresponded to the number of sub-sectors, i.e., 50.

Indeed, as the data presented in Table 9 show, the following quadratic relationships exist:

- (1) between I_e and s_0 . The minimum values of the dependent variable of the regression equation correspond to the mean values of s_0 . The presence of this dependence indirectly confirms the validity of hypothesis 1 expressed in Section 3.3;
- (2) between ΔC_{op} and s_0 . In this case, with increasing s_0 , the value of the dependent variable of the regression equation ΔC_{op} increases over the entire range of s_0 values that are considered. The presence of this dependence indirectly confirms the validity of hypothesis 2 expressed in Section 3.3;
- (3) between I_{Va} and s_0 . The maximum values of the dependent variable of regression equation I_{Va} exceed 1.0 and correspond to the mean values of s_0 . The presence of this dependence indirectly confirms the validity of hypothesis 3 expressed in Section 3.3;
- (4) between I_{Va} and I_e . In this case, this dependence is a descending one over the entire range of I_e values that are under consideration. Consequently, as I_e decreases (and, consequently, increases the efficiency of natural gas use by the Ukrainian industry), I_{Va} (value added index) increases. This conclusion partly accounts for the validity of hypothesis 3 in Section 3.3.

Table 9. The results of the regression analysis of the relationship between individual indicators of activity of industry sub-sectors of Ukraine.

Indicators between which Dependencies are Established		Regression Coefficients			Indicators of Regression Equations					Tests for the Normality of the Distribution of Regression Residues		White Test	
					R ²	F-Value	t-Value						
		Dependent	Independent	β ₀			β ₁	β ₂			t _{β0}	t _{β1}	t _{β2}
I _e	s ₀	1.129*	−0.161*	0.011*	0.505	23.93	10.43	5.50	6.15	0.065	0.978	0.001	0.011
ΔC _{op}	s ₀	3.394*	−0.725*	0.076*	0.694	53.21	3.36	2.30	4.02	0.082	0.975	0.142	3.892
I _{Va}	s ₀	0.542*	0.141*	−0.010*	0.259	8.20	2.44	2.36	2.89	0.150	0.947	0.073	1.876
I _E	s ₀	0.607*	−0.020	0.001	0.002	0.05	2.60	0.32	0.30	0.059	0.975	0.044	1.091
I _{Va}	I _e	3.390*	−6.198*	3.401*	0.490	22.62	7.18	4.89	4.21	0.134	0.929	0.034	0.837

Note: *—a mark for those β_0 , β_1 and β_2 that are statistically significant at the 0.05 level. **—Shapiro-Wilk test. ***—Regression indicators between regression residual squares and independent variables

However, there is no linear or quadratic relationship between I_E and s_0 as evidenced by the low F-value (Table 9).

In this case, as follows from the data presented in Table 9, by the selected criteria, the residuals for all regression dependencies are subject to the normal law of distribution. However, according to White's test, the residuals of the regression relationship between ΔC_{op} and s_0 are characterized by some level of heteroscedasticity. However, all other regression dependencies meet the condition of homoscedasticity.

Therefore, the increase of natural gas efficiency in the Ukrainian industry in 2012–2016 was mainly in the industry sub-sectors with average values. This, in turn, has caused energy-saving economic growth in natural gas in most of these sub-sectors.

It should be noted that the unevenness of the change in the efficiency of natural gas consumption in various industries of Ukraine, along with the differences in the dynamics of their added value, may lead to structural changes in the consumption of natural gas in all the aggregate industries. Using the expressions (B1)–(B3) (Appendix B), in Table 10 we evaluated the impact of structural changes on the change in the volume of natural gas consumption in the aggregate industries of Ukraine.

Table 10. Input information and results of the assessment of the impact of structural changes and other factors on the change in natural gas consumption by aggregate industrial sectors of Ukraine in 2016 compared to 2012 ¹.

Indicator Names	Changes in Natural Gas Consumption in 2016 Compared to 2012			
	In the Totality of Industry Sectors	Due to the Change in the Aggregate Real Value Added	Due to Changes in Sectoral Interrelations between Gas Consumption and Real Value Added	Due to Changes in the Sectoral Structure of Gas Consumption
Absolute change in volume of natural gas consumption, thousand tons of oil equivalent	−2793	−1033	−1418	−342
Change in natural gas consumption as a percentage of the total change in its consumption in all industries, %	100.00	36.99	50.77	12.24

¹ Sources of input information: [65–67].

As follows from the data presented in Table 10, all considered factors of influence on changes in natural gas consumption caused the reduction of its consumption volumes in the aggregate of industrial sectors of Ukraine in 2016 compared to 2012. However, as follows from the data of the last column of Table 10, the effect of structural changes on the reduction of natural gas consumption was not very strong and it was 12.24% of the total value of such a decrease.

4.4. Analysis of State Support for Measures to Reduce Natural Gas Consumption by Non-Commercial Consumers in Ukraine

It should be noted that, besides industry, significant volumes of natural gas consumption in Ukraine fall into other sectors of the economy. These sectors can be divided into three groups, namely:

(1) commercial consumers (except those generating heat energy), including industry, transport, commerce and other sectors that create added value;

(2) commercial consumers who work in the field of heat generation (first of all, they include the thermal power plants);

(3) non-commercial consumers (first of all, the household sector and budgetary institutions).

As follows from the information presented in Figure 9, the rate of change in natural gas consumption for the aforementioned three categories of its customers significantly differ. So the volume of natural

gas consumption in 2017 compared to 2007 decreased by 67.3% for first category of consumers and for non-commercial consumers this reduction was only 29.1%.

Figure 9. The rate of change in natural gas consumption relative to 2007 (times) by sectors of the Ukrainian economy, where 1—commercial consumers (except for heat generation), 2—commercial consumers who generate heat energy, and 3—non-commercial consumers [62,65].

The high heat losses in residential buildings are the main reason for the high consumption of natural gas by non-profit consumers in Ukraine. However, the most of Ukrainian households are not able to pay for saving measures of natural gas due to their low incomes. In this regard, the Government of Ukraine is implementing a household lending program to realize such measures. In this case, the state is reimbursed from 20% to 40% of the value of such expenditures. At the same time, the term of lending is small and is usually about three years, and the interest rate is high—about 18% per annum.

We should note that the models of economic barriers to implementation of energy saving technologies at enterprises can be extrapolated in the form of formulas (A1)–(A7) (Appendix A) for implementing measures to save natural gas by households, in particular, thermo-modernization of residential buildings. Indeed, in this case we can see two main economic barriers, namely:

(1) insufficient efficiency of investments in natural gas saving measures, when saving on payments for natural gas is less than the amount of interest on a loan. In other words, the ratio of cost savings on natural gas consumption to the amount of interest on the loan is less than one. Then the difference between one and the magnitude of this ratio will characterize the first kind of barriers to the implementation of measures for natural gas savings in residential buildings;

(2) the lack of adequate income for households to repay the loan taken for the implementation of measures for natural gas savings in residential buildings, and to pay interest on this loan. In other words, the ratio of a part of the average annual income of a household that can be used to repay a loan to the value of annual loan payments is less than one. Then the difference between one and the magnitude of this ratio will characterize the second kind of barriers to the implementation of measures to save on natural gas in residential buildings.

Based on data on the average cost of various measures to save on natural gas consumption in residential buildings [11], the magnitude of this savings from the implementation of appropriate measures [68], the average amount of payments for credit [69], income and expenditure of households [66], Table 11 presents the results of calculation of the level of economic barriers to the implementation of measures to reduce consumption of natural gas in residential buildings.

Table 11. Averaged levels of economic barriers to implementing measures to reduce consumption of natural gas in residential buildings in Ukraine and indicators of the efficiency of public expenditures for partial compensation of loan amount taken for these activities.

Indicator Names	Averaged Values of Indicators by Measures to Reduce Consumption of Natural Gas in Residential Buildings				
	Installation of Heat-Saving Windows on Balcony Doors	Insulation of External Walls of Buildings	Replacement of Gas Boilers for Solid Fuel Boilers	Installation of Air Temperature Controllers	Installation of Heat Recuperators of Ventilation Air
Economic barriers level to implementing measures to save on natural gas consumption in residential buildings, share of unit					
first kind of barriers	0.22	0.14	0.27	0.32	0.29
second kind of barriers	0.41	0.35	0.45	0.49	0.50
generalized assessment of barriers	0.41	0.35	0.45	0.49	0.50
Efficiency of public expenditures on partial compensation of loan, USD. per 1 m ³ of natural gas savings	0.32	0.27	0.36	0.39	0.40

As the data in Table 11 shows, a generalized assessment of the barriers to implementing measures to reduce the natural gas consumption in residential buildings, for most of these measures, exceeds 0.4. Therefore, in order to significantly increase the implementation of measures to save natural gas in the residential sector of Ukraine, it is necessary to increase the proportion of state compensation for loans taken for these measures. It is also worth noting that the level of the second kind of barriers is higher than the level of barriers of first kind by all measures. It follows that the further increase of prices for natural gas for the population of Ukraine will not cause a stimulating effect on the implementation of the considered measures for the natural gas saving.

4.5. Estimation of the Potential of Reduction of Natural Gas Consumption by the Economy of Ukraine and Possibilities of Achieving Energy Independence from its Import

The general tendency to reduce the consumption of natural gas by the economy of Ukraine during 2007–2017 led to a gradual decrease in the level of dependence on its imports. In particular, as follows from the data presented in Table S9 (Supplementary), the relative level of this dependency decreased from 71.35% in 2007 to 38.41% in 2017. However, this reduction was mainly due to a decrease in natural gas consumption, since its own production for the period under study did not significantly increase.

According to estimates submitted in particular by [68], Ukraine has the potential to reduce the consumption of natural gas by non-commercial consumers by 2.4 billion cubic meters over five years and the consumption of natural gas for heat generation can decrease by 2.6 billion cubic meters. At the same time, the average expected growth rate of Ukraine's GDP is about 3% per year. It should also be borne in mind that in 2017 commercial consumers of natural gas in Ukraine (with the exception of heat generation) consumed about 10 billion cubic meters. Let us assume that the efficiency of using natural gas by these consumers will remain unchanged, and the growth rate of real value added will be 3% per year. Then, due to the reduction of natural gas consumption by non-profit consumers and those who carry out heat generation, the energy-saving economic growth by natural gas will occur during a certain period in the economy of Ukraine. The predicted duration of this period T can be determined from the following equation: $10 \cdot (1 + 0.03)^T - 10 = 2.4 + 2.6$, from where T is equal to 13.7 years. Thus, the Ukrainian economy may consume less natural gas than it consumed in 2017 for at least 13.7 years. However, ensuring the energy independence of Ukraine's economy from natural gas supplies will not

succeed. This is due to the fact that the expected reduction of natural gas consumption is significantly lower than the absolute value of the level of dependence on imports of natural gas. At the same time, according to estimates made by experts [68], Ukraine may increase its own natural gas production by about 7 billion cubic meters for five years.

Taking into account the above, Table 12 presents the input data and the results of calculating the relative level of dependence of the Ukrainian economy on imports of natural gas for various combinations of input data. Also, the maximum possible values of the GDP index, which will achieve full energy independence from the import of natural gas, are presented in this table. These values are calculated by Equation (19).

Table 12. Input data and results of calculation of the forecast level of dependence of the Ukrainian economy on natural gas imports in 2022 under different scenarios of the relations of the values of the raw data.

Indicator Names	Values of Indicators in Different Scenarios					
	I	II	III	IV	V	VI
The five-year GDP index at an annual GDP growth rate of 3%	1.16	1.16	1.16	1.16	1.16	1.16
Five-year index of the efficiency of natural gas use by commercial consumers (except those that carry out heat generation)	1.00	1.25	1.00	1.25	1.00	1.25
Reduction of natural gas consumption by non-commercial consumers and in order to generate heat during five years, billion cubic meters	5.0	5.0	0.0	0.0	5.0	5.0
Increase of own production of natural gas during five years, billion cubic meters	0.0	0.0	7.0	7.0	7.0	7.0
Relative forecasted level of dependence of Ukraine's economy on imports of natural gas, %	0.310	0.247	0.202	0.142	0.060	-0.024
The maximum possible value of the five-year GDP index, which in which full independence of the energy economy on natural gas imports could be achieved	0.290	0.363	0.490	0.613	0.990	1.238

According to the data presented in Table 12, the achievement of Ukraine's energy independence from natural gas supplies is possible only if it simultaneously reduces its consumption (by non-commercial consumers and those generating heat energy) and increase its own production. Under such conditions, the Ukrainian economy can achieve independence from natural gas supplies, even with a higher five-year GDP index (1.238 instead of planned 1.16). At the same time, increasing the efficiency of natural gas use by commercial consumers (except for heat generation) does not significantly affect the level of dependence on imports of natural gas. This is due to the relatively small (about 30%) share of this category of consumers in the total volume of natural gas consumption by the Ukrainian economy in 2017. However, the combined effect of all these factors may lead to the fact that in 2022 Ukraine may become an exporter of natural gas.

5. Conclusions

The research showed that there are six main types of correlation between the change in sectoral volumes of consumption of certain energy resources and the change in sectoral value added. In turn, the specific type of these ratios, which is implemented in practice, depends on the values of the three

indices, namely: the sectoral index of physical volumes of sales of products, the sectoral index of value added per unit of physical volume of production and the sectoral index of volumes of consumption of certain energy per unit of physical volume of production. In order to reduce the industry's consumption of certain energy resources accompanied by the growth of sectoral value added, the sectoral index of physical volumes of sales should fall within a certain range, the boundaries of which are determined by two other indices. At the same time, the limits of the specified range and its length essentially depend on the value of the sectoral index of the efficiency of the use of energy resources. We proposed to evaluate this efficiency by the ratio between sectoral added value and sectoral energy consumption.

In this work, the model of the influence of factors on the change of added value and volumes of consumption of a certain type of energy resources in the industry was constructed. In turn, it is necessary to realize an analysis of this model by using the decomposition method that is developed in the work of the growth rate of the sectoral efficiency of the use of certain energy resources. This method takes into account a number of factors of influence, in particular, changes in energy prices, their use per unit of output, etc. At the same time, interrelation was established between the indicators of the constructed model, in particular, the deterministic and statistical dependencies between them were distinguished.

Also, the authors identified the main methods of adapting the industry to increasing prices for a certain energy resource, namely: by increasing the prices for the products of the industry and by reducing the cost of energy per unit of physical volume of production. At the same time, we expressed hypotheses that the choice of certain methods of adaptation or a certain combination of them largely depends on the share of the cost of purchasing energy resources in total sectoral operating costs.

In general, the change in the sectoral structure of energy consumption can have a significant impact on both the change in the aggregate value of this consumption of industries and on the change in added value. At the same time, theoretically possible is the case when there is no energy-saving economic growth in each of the economic sectors, but it is observed in the whole set of branches. In order for this to happen, the existence of two groups of industries is necessary: the added value of one group should increase with the simultaneous increase of energy consumption, and the tendency of other group of industries should be reversed. Then, the energy-saving economic growth in the aggregate of industries is possible with a certain combination of values of these indicators by these industries. In general, if there is a decline in added value among the industries under consideration, the best option is to reduce the added value in the most energy-intensive industries from the point of view of ensuring the aggregate of all sectors of energy-saving economic growth. Such industries are those that represent the largest ratio between the amount of energy consumption and added value.

The empirical analysis showed that achieving economic growth with simultaneous reduction of natural gas consumption is inherent in certain periods of time in economies of many countries. This also applies to Ukraine. For example, in 2013, compared with 2009, its real GDP grew from 344.5 billion USD to 379.3 billion USD, while natural gas consumption decreased from 51.9 billion cubic meters to 50.4 billion cubic meters.

In general, during 2007–2017, natural gas consumption in the Ukrainian economy decreased more than twice. This was supported by a significant increase in domestic prices for natural gas during the period under study, as well as a high base level of natural gas use in production.

A number of industry sectors in Ukraine during 2007–2017 achieved a significant reduction of this level. In this regard, for some industries in Ukraine, increasing the use of natural gas has had a significant impact on the overall decline in its consumption. The greatest impact during 2007–2017 was in the wood processing industry (94.65%), in the production of nonmetallic mineral products (81.7%), as well as in the chemical and petrochemical industry (72.31%).

The sectoral analysis of the Ukrainian industry showed that, firstly, the majority of industry sectors in which the index of natural gas consumption per unit of physical output is low, are characterized by average values of the share of expenses for the purchase of this energy resource in total operating expenses. Secondly, most industries with low relative growth of operating costs due to the increase in

natural gas prices are characterized by low or average value of the share of the cost of purchasing this energy resource in the volume of operating expenses. Thirdly, energy-saving economic growth by natural gas happened predominantly in sectors with an average share of the cost of purchasing this energy in the volume of operating expenses.

It was also found that the share of costs for the purchase of natural gas in the volume of operating costs of Ukrainian industries shows a positive correlation with the increase in operating costs due to the increase in natural gas prices. At the same time, the share of costs for the purchase of natural gas in the amount of operating expenses of Ukrainian industries shows a negative correlation with the natural gas consumption index

Among other things, the work identified factors contributing to the fact that the growth of value added of certain industries of Ukraine took place simultaneously with the reduction of natural gas consumption. In particular, it has been established that energy-saving economic growth by natural gas occurred mainly in sectors with an average share of the cost of purchasing this energy in total operating costs.

At the same time, the impact of structural changes on the reduction of natural gas consumption was not very strong at the aggregate level of all the industries under consideration in Ukraine. In particular, in 2016, compared with 2012, the magnitude of this effect was only 18% of the total volume of natural gas consumption reduction.

Among other things, a study showed that the Ukrainian economy has the potential to weaken dependence on natural gas imports and even to achieve energy independence from its import supplies. This is possible, first of all, by reducing the consumption of natural gas by non-profit consumers, as well as by the sector that generates heat. Under such conditions, the projected duration of energy-saving economic growth by natural gas of the Ukrainian economy is 13.7 years. However, the achievement of the necessary reduction of natural gas consumption requires, in particular, an increase in the share of state compensation of loans taken by Ukrainian households to implement measures for the natural gas saving.

However, the achievement of Ukraine's energy independence from imports of natural gas is possible only if, along with the reduction of its consumption, its own production will increase. This requires an increase in state investments in gas extraction, the creation of a transparent system of auctions for the right to extract gas, reducing the rent for the extraction of natural gas, etc.

6. Limitations and Prospects for Further Research

In this paper, an index method for modeling the influence of factors on natural gas consumption and sectoral value added was applied. The accuracy of this method is due to the accuracy of the calculations of the corresponding indices calculated by the state statistical authorities. It should also be noted that not all interconnections between factors affecting the change in value added and volumes of natural gas consumption in Ukrainian industries were considered. In particular, beyond the research performed, the effect of rebound of natural gas consumption remained. Also, further development perspectives include the construction of a criterion for optimizing the relationship between economic growth and the level of energy dependence of countries. Finally, it is advisable to further explore the driving forces of energy-saving economic growth, in particular, the role played by this emergence of new energy-saving technologies.

Supplementary Materials: The following are available online at <http://www.mdpi.com/1996-1073/12/24/4724/s1>, Table S1: Indicators of the ratio between real GDP and natural gas consumption by country, Table S2: Input data and decomposition results of the growth rate of natural gas consumption by Ukrainian industry for 2008–2017, Table S3: Input data and results of decomposition of changes in volumes of natural gas consumption by industry sectors of Ukraine in 2017 compared to 2007, Table S4: Indicators of the dynamics of added value and volumes of natural gas consumption in industry in Ukraine for 2008–2017, Table S5: Indicators of the dynamics of added value and volumes of natural gas consumption by industries of Ukraine in 2008–2016, Table S6: Input data to determine the impact of the share of costs on purchasing natural gas in the amount of operating costs by industry in Ukraine on the change in the efficiency of consumption of natural gas, Table S7: Division of Ukrainian industry sectors

into sub-sectors, Table S8: Some indicators of activity of industry sub-sectors of Ukraine, Table S9: Dynamics of natural gas consumption and production in Ukraine and indicators of dependence on its import for 2007–2017.

Author Contributions: O.Y., O.Z., T.P., R.L. and M.K. conceived and designed the research; A.S. and T.P. provided theoretical guidance; A.S. and R.L. interpreted and discussed the data; M.K. and L.L. analyzed the quantitative data; O.Y. and L.L. wrote the paper. All authors read and approved the final manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Modeling Barriers to the Implementation of Energy-Efficient Technologies

The main conditions for the feasibility of implementing energy-saving technologies in enterprises are as follows:

(1) replacement of existing technology with energy-saving technology should provide for a company that plans to implement this technology a sufficiently large profit increase, that is, such inequality must be met:

$$p_{re} \cdot (N_0 - N_1) - c_{et} > i_n \cdot N_i, \quad (A1)$$

where p_{re} —price of a unit of energy, the consumption of which is supposed to be reduced as a result of the implementation of energy-saving technology at the enterprise; N_0, N_1 —physical volumes of energy consumption per unit of output in accordance with existing and energy-saving technologies; c_{et} —other costs associated with the implementation of energy-saving technology, per unit of output (to these costs, in particular, we may include additional costs for other energy resources if it is intended to replace the energy resource whose consumption is expected to be reduced); i_n —volume of necessary investments in the implementation of energy-saving technology per unit of output; N_i —minimum allowable return on investment (in particular, it can be the interest rate if financing of energy-saving technology is foreseen due to loan);

(2) the company must have sufficient financial resources to implement energy-saving technology. In particular, if financing of such implementation is carried by a bank loan, the enterprise should receive a sufficiently large cash flow in order to repay the borrowed in a timely manner. In other words, the following inequality must be fulfilled:

$$F_C \geq F_R = C_{inv} \cdot r, \quad (A2)$$

where F_C —annual cash flow that an enterprise can use to repay a loan that will be taken to finance the implementation of energy-saving technology; F_R —annual flow of return of the main amount of the loan taken and accrued interest; C_{inv} —investment needed to implementing energy-saving technology; r —ratio between the annual flow of credit payments and the amount of required investment ($r = F_R/C_{inv}$).

Assume now that the inequalities (A1) and (A2) are not met. This means that there are economic barriers to the implementation of energy saving technology. In this case, the barrier that arises as a result of non-fulfillment of inequality (A1), will be called an economic barrier of the first type. The barrier that arises as a result of non-fulfillment of the inequality (A2) will be called an economic barrier of the second type.

It is possible to estimate the level of these barriers by establishing the minimal relative amount of investment reduction in the implementation of energy-saving technology, in which the inequalities (A1) and (A2) will be fulfilled:

$$p_{re} \cdot (N_0 - N_1) - c_{et} = i_n \cdot (1 - k_1) \cdot N_i, \quad (A3)$$

$$F_C = C_{inv} \cdot (1 - k_2) \cdot r, \quad (A4)$$

where k_1 , k_2 —the minimal relative value of the decrease in the volume of investment in the implementation of energy saving technology, in which the inequality (A1) and inequality (A2), respectively, will be fulfilled, and share of unit.

From the equalities (A3) and (A4) we obtain:

$$k_1 = 1 - \frac{p_{re} \cdot (N_0 - N_1) - c_{et}}{i_n \cdot N_i}, \quad (A5)$$

$$k_2 = 1 - F_C / (C_{inv} \cdot r), \quad (A6)$$

Thus, a generalized assessment of economic barriers to the implementation of energy-saving technology can be made using the following expression:

$$k = \max\{0, k_1, k_2\}, \quad (A7)$$

where k —indicator of a generalized assessment of economic barriers towards the implementation of energy saving technology.

At the same time, the zero value of the indicator k will mean the absence of economic barriers to the implementation of energy-saving technology.

Appendix B

Decomposition Model of Changes in Consumption of Certain Energy Resources

This model is as follows:

$$\Delta E_1 = \left(\sum_{i=1}^n V_{a1i} - \sum_{i=1}^n V_{a0i} \right) \cdot \left(\left(\sum_{i=1}^n E_{0i} \right) / \left(\sum_{i=1}^n V_{a0i} \right) \right), \quad (A8)$$

$$\Delta E_2 = \sum_{i=1}^n \left(V_{a0i} \cdot \left(\left(\sum_{i=1}^n V_{a1i} \right) / \left(\sum_{i=1}^n V_{a0i} \right) \right) \cdot \left(\frac{E_{1i}}{V_{a1i}} - \frac{E_{0i}}{V_{a0i}} \right) \right), \quad (A9)$$

$$\Delta E_3 = \sum_{i=1}^n E_{1i} - \sum_{i=1}^n E_{0i} - \Delta E_1 - \Delta E_2, \quad (A10)$$

where ΔE_1 , ΔE_2 , ΔE_3 —change in the volume of consumption of certain energy resources in the totality of economic sectors, respectively: due to changes in the aggregate added value of industries, due to changes in sectoral ratios between the consumption of certain energy resources and the amount of added value, due to changes in the sectoral structure of consumption of this energy resource; n —the number of branches of the economy under consideration; V_{a1i} , V_{a0i} —the amount of the added value of the “ i ” industry, respectively, in the reporting and baseline periods; E_{0i} , E_{1i} —volume of consumption of certain energy resources by enterprises of the “ i ” industry, respectively, in the base and reporting periods.

References

1. Valdés Lucas, J.N.; Escribano Francés, G.; San Martín González, E. Energy security and renewable energy deployment in the EU: Liaisons dangereuses or virtuous circle? *Renew. Sustain. Energy Rev.* **2016**, *62*, 1032–1046. [\[CrossRef\]](#)
2. Duffield, J.S. *Fuels Paradise. Seeking Energy Security in Europe, Japan, and the United States*; Johns Hopkins University Press: Baltimore, MD, USA, 2015; p. 384. ISBN 9781421416731.
3. Nyman, J. Rethinking energy, climate and security: A critical analysis of energy security in the US. *J. Int. Relat. Dev.* **2018**, *21*, 118–145. [\[CrossRef\]](#)

4. McCauley, S.M.; Stephens, J.C. Green energy clusters and socio-technical transitions: Analysis of a sustainable energy cluster for regional economic development in Central Massachusetts, USA. *Sustain. Sci.* **2012**, *7*, 213–225. [CrossRef]
5. Cantore, N.; Calì, M.; Velde, D.W. Does energy efficiency improve technological change and economic growth in developing countries? *Energy Policy* **2016**, *92*, 279–285. [CrossRef]
6. Proedrou, F. *EU Energy Security in the Gas Sector: Evolving Dynamics, Policy Dilemmas and Prospects*; Ashgate: Farnham, UK, 2012; p. 171. ISBN 9781409438052.
7. Davis, C.M. The Ukraine conflict, economic–military power balances and economic sanctions. *J. Post Communist Econ.* **2016**, *28*, 167–198. [CrossRef]
8. Van de Graaf, T.; Colgan, J.D. Russian gas games or well-oiled conflict? Energy security and the 2014 Ukraine crisis. *Energy Res. Soc. Sci.* **2017**, *24*, 59–64. [CrossRef]
9. Wolczuk, K. Managing the flows of gas and rules: Ukraine between the EU and Russia. *Eurasian Geogr. Econ.* **2016**, *57*, 113–137. [CrossRef]
10. Comments and Suggestions for the Energy Strategy of Ukraine for the Period up to 2035. 2018. Available online: http://necu.org.ua/wp-content/uploads/NECU_proposals_energy_strategy2035.pdf (accessed on 25 June 2019).
11. Warm Loans. Privatbank. Available online: <https://privatbank.ua/teplyje-kredyty-uteplajems-a-vmeste> (accessed on 26 June 2019).
12. National Institute of Strategic Studies. Energy Efficiency at Regional Terms. Problems and Prospects. Available online: <http://www.niss.gov.ua/content/articles/files/energoeffekt-b40dc.pdf> (accessed on 26 June 2019).
13. Salahuddin, M.; Alam, K.H. Information and communication technology, electricity consumption and economic growth in OECD countries: A panel data analysis. *Int. J. Electr. Power* **2016**, *76*, 185–193. [CrossRef]
14. Rafindadi, A.A.; Ozturk, I. Natural gas consumption and economic growth nexus: Is the 10th Malaysian plan attainable within the limits of its resource? *Renew. Sustain. Energy Rev.* **2015**, *49*, 1221–1232. [CrossRef]
15. Furuoka, F. Natural gas consumption and economic development in China and Japan: An empirical examination of the Asian context. *Renew. Sustain. Energy Rev.* **2016**, *56*, 100–115. [CrossRef]
16. Solarin, S.A.; Ozturk, I. The relationship between natural gas consumption and economic growth in OPEC members. *Renew. Sustain. Energy Rev.* **2016**, *58*, 1348–1356. [CrossRef]
17. Fadiran, G.; Adebuseyi, A.T.; Fadiran, D. Natural gas consumption and economic growth: Evidence from selected natural gas vehicle markets in Europe. *Energy* **2019**, *169*, 467–477. [CrossRef]
18. Angeliki, N.M.; Tugcu, C.T. Energy consumption and Sustainable Economic Welfare in G7 countries; A comparison with the conventional nexus. *Renew. Sustain. Energy Rev.* **2017**, *69*, 892–901.
19. Paramati, S.R.; Bhattacharya, M.; Ozturk, I.; Zakari, A. Determinants of energy demand in African frontier market economies: An empirical investigation. *Energy* **2018**, *148*, 123–133. [CrossRef]
20. Cucciella, F.; D'Adamo, I.; Gastaldi, M. Future trajectories of renewable energy consumption in the European Union. *Resources* **2018**, *7*, 10. [CrossRef]
21. Bhattacharya, M.; Paramati, S.R.; Ozturk, I.; Bhattacharya, S. The effect of renewable energy consumption on economic growth: Evidence from top 38 countries. *Appl. Energy* **2016**, *162*, 733–741. [CrossRef]
22. Lper, A.; Oguz, O. The role of renewable energy consumption in economic growth: Evidence from asymmetric causality. *Renew. Sustain. Energy Rev.* **2016**, *60*, 953–959.
23. Koçak, E.; Şarkgüneşi, A. The renewable energy and economic growth nexus in Black Sea and Balkan countries. *Energy Policy* **2017**, *100*, 51–57. [CrossRef]
24. Akinlo, A.E. Energy consumption and economic growth: Evidence from 11 Sub-Sahara African countries. *Energy Econ.* **2008**, *30*, 2391–2400. [CrossRef]
25. Ozturk, I. A literature survey on energy–growth nexus. *Energy Policy* **2010**, *38*, 340–349. [CrossRef]
26. Gillingham, K.; Rapson, D.; Wagner, G. The rebound effect and energy efficiency policy. *Rev. Environ. Econ. Policy* **2016**, *10*, 68–88. [CrossRef]
27. Wang, Z.; Han, B.; Lu, M. Measurement of energy rebound effect in households: Evidence from residential electricity consumption in Beijing, China. *Renew. Sustain. Energy Rev.* **2016**, *58*, 852–861. [CrossRef]
28. Howarth, R.B. Energy efficiency and economic growth. *Contemp. Econ. Policy* **1997**, *15*, 1–9. [CrossRef]
29. Zhang, J.; Lin Lawell, C.-Y.C. The macroeconomic rebound effect in China. *Energy Econ.* **2017**, *67*, 202–212. [CrossRef]

30. Qingsong, W.; Zhenlei, G.; Hongrui, T.; Xueliang, Y.; Jian, Z. Exploring the direct rebound effect of energy consumption: A case study. *Sustainability* **2018**, *10*, 1–21.
31. Orea, L.; Llorca, M.; Filippini, M. A new approach to measuring the rebound effect associated to energy efficiency improvements: An application to the US residential energy demand. *Energy Econ.* **2015**, *49*, 599–609. [[CrossRef](#)]
32. Yoo, S.H.; Lee, J.S. Electricity consumption and economic growth: A cross-country analysis. *Energy Policy* **2010**, *38*, 622–625. [[CrossRef](#)]
33. Pablo-Romero, M.P.; De Jesús, J. Economic growth and energy consumption: The energy-environmental Kuznets curve for Latin America and the Caribbean. *Renew. Sustain. Energy Rev.* **2016**, *6*, 1343–1350. [[CrossRef](#)]
34. Bouznit, M.; Pablo-Romero, M.P.; Sánchez-Braza, A. Residential electricity consumption and economic growth in Algeria. *Energies* **2018**, *11*, 1656. [[CrossRef](#)]
35. Thollander, P.; Kimura, O.; Wakabayashi, M.; Rohdin, P. A review of industrial energy and climate policies in Japan and Sweden with emphasis towards SMEs. *Renew. Sustain. Energy Rev.* **2015**, *50*, 504–512. [[CrossRef](#)]
36. Hassler, J.; Krusell, P.; Olovsson, C. *Energy-Saving Technical Change*; NBER Working Paper, No. 18456; NBER: Cambridge, MA, USA, 2012.
37. Johansson, M.T.; Thollander, P. A review of barriers to and driving forces for improved energy efficiency in Swedish industry—Recommendations for successful in-house energy management. *Renew. Sustain. Energy Rev.* **2018**, *82*, 618–628. [[CrossRef](#)]
38. Trianni, A.; Cagno, E.; Worrell, E.; Pugliese, G. Empirical investigation of energy efficiency barriers in Italian manufacturing SMEs. *Energy* **2013**, *49*, 444–458. [[CrossRef](#)]
39. Zhang, Z.; Jin, X.; Yang, Q.; Zhang, Y. An empirical study on the institutional factors of energy conservation and emissions reduction: Evidence from listed companies in China. *Energy Policy* **2013**, *57*, 36–42. [[CrossRef](#)]
40. Kostka, G.; Moslener, U.; Andreas, J. Barriers to increasing energy efficiency: Evidence from small-and medium-sized enterprises in China. *J. Clean. Prod.* **2013**, *57*, 59–68. [[CrossRef](#)]
41. Rohdin, P.; Thollander, P. Barriers to and driving forces for energy efficiency in the non-energy intensive manufacturing industry in Sweden. *Energy* **2006**, *31*, 1836–1844. [[CrossRef](#)]
42. Trianni, A.; Cagno, E.; Worrell, E. Innovation and adoption of energy efficient technologies: An Exploratory analysis of Italian primary metal manufacturing SMEs. *Energy Policy* **2013**, *61*, 430–440. [[CrossRef](#)]
43. Yemelyanov, O.; Symak, A.; Petrushka, T.; Lesyk, R.; Lesyk, L. Assessment of the technological changes impact on the sustainability of state security system of Ukraine. *Sustainability* **2018**, *10*, 1186. [[CrossRef](#)]
44. Shipan, C.; Volden, C. The mechanisms of policy diffusion. *Am. J. Political Sci.* **2008**, *52*, 840–857. [[CrossRef](#)]
45. Lesinskiy, V.; Yemelyanov, O.; Zarytska, O.; Symak, A.; Koleshchuk, O. Substantiation of projects that account for risk in the resource-saving technological changes at enterprises. *East. Eur. J. Enterp. Technol.* **2018**, *6*, 1. [[CrossRef](#)]
46. Abolhosseini, S.; Heshmati, A. The main support mechanisms to finance renewable energy development. *Renew. Sustain. Energy Rev.* **2014**, *40*, 876–885. [[CrossRef](#)]
47. He, L.; Ding, Z.; Yin, F.; Wu, M. The impact of relative energy prices on industrial energy consumption in China: A consideration of inflation costs. *Springerplus* **2016**, *5*, 1001. [[CrossRef](#)] [[PubMed](#)]
48. Ju, K.; Su, B.; Zhou, D.; Liu, L. Macroeconomic performance of oil price shocks: Outlier evidence from nineteen major oil-related countries/regions. *Energy Econ.* **2016**, *60*, 325–332. [[CrossRef](#)]
49. Vandyck, T.; Kitous, A.; Saveyn, B.; Keramidas, K.; Los Santos, L.R.; Wojtowicz, K. Economic exposure to oil price shocks and the fragility of oil-exporting countries. *Energies* **2018**, *11*, 827. [[CrossRef](#)]
50. Bretschger, L. Energy prices, growth, and the channels in between: Theory and evidence. *Resour. Energy Econ.* **2015**, *39*, 29–52. [[CrossRef](#)]
51. Zhao, L.; Zhang, X.; Wang, S.; Xu, S. The effects of oil price shocks on output and inflation in China. *Energy Econ.* **2016**, *53*, 101–110. [[CrossRef](#)]
52. Narayan, P.; Narayan, S. Modelling the impact of oil prices on Vietnam's stock prices. *Appl. Energy* **2010**, *87*, 356–361. [[CrossRef](#)]
53. Korsakienė, R.; Tvaronavičienė, M.; Smaliukienė, R. Impact of energy prices on industrial sector development and export: Lithuania in the context of Baltic States. *Procedia Soc. Behav. Sci.* **2014**, *110*, 461–469. [[CrossRef](#)]
54. Chen, Y.-T. The factors affecting electricity consumption and the consumption characteristics in the residential sector—A case example of Taiwan. *Sustainability* **2017**, *9*, 1484. [[CrossRef](#)]

55. Nesbakken, R. Price sensitivity of residential energy consumption in Norway. *Energy Econ.* **1999**, *21*, 493–515. [CrossRef]
56. Yemelyanov, O.; Symak, A.; Petrushka, T.; Lesyk, R.; Lesyk, L. Evaluation of the adaptability of the Ukrainian economy to changes in prices for energy carriers and to energy market risks. *Energies* **2018**, *11*, 3529. [CrossRef]
57. Jongerden, M.R.; Hüls, J.; Haverkort, B.R.; Remke, A. Assessing the cost of energy independence. In Proceedings of the 2016 IEEE International Energy Conference (ENERGYCON), Leuven, Belgium, 4–8 April 2016.
58. Kim, S.-Y.; Choi, H.-S.; Eum, J.-H. Energy-independent architectural models for residential complex plans through solar energy in Daegu Metropolitan City, South Korea. *Sustainability* **2018**, *10*, 482. [CrossRef]
59. Skiba, M.; Mrówczyńska, M.; Bazan-Krzywoszańska, A. Modeling the economic dependence between town development policy and increasing energy effectiveness with neural networks. Case study: The town of Zielona Góra. *Appl. Energy* **2017**, *188*, 356–366. [CrossRef]
60. Luo, X.; Wang, J.; Dooner, M.; Clarke, J. Overview of current development in electrical energy storage technologies and the application potential in power system operation. *Appl. Energy* **2015**, *137*, 511–536. [CrossRef]
61. Bompard, E.; Carpaneto, E.; Huang, T.; Pi, R.J.; Fulli, G.; Purvins, A.; Mutule, A. Electricity independence of the Baltic States: Present and future perspectives. *Sustain. Energy Grids Netw.* **2017**, *10*, 55–64. [CrossRef]
62. Energy Efficiency Trends and Policies in Industry. Available online: <http://www.odyssee-mure.eu/publications/br/energy-efficiency-in-industry.html> (accessed on 26 June 2019).
63. BP Statistical Review of World Energy 2018. 2018. Available online: <http://agpu.org.ua/upload/files/10153122706935.pdf> (accessed on 26 June 2019).
64. GDP, at Constant 2010 Prices (US \$). Available online: <https://knoema.com/atlas/topics/Economy/National-Accounts-Gross-Domestic-Product/Real-GDP> (accessed on 26 June 2019).
65. State Statistic Service of Ukraine. Economic Statistics/Economic Activity/Energy. Available online: <http://www.ukrstat.gov.ua/> (accessed on 26 June 2019).
66. Ukrstat.org—State Statistics Service of Ukraine Documents Publishing. Available online: <https://ukrstat.org/en> (accessed on 26 June 2019).
67. Activity of Economic Entities. Statistical Collection 2017. Available online: http://www.ukrstat.gov.ua/druk/publicat/kat_u/publ9_u.htm (accessed on 26 June 2019).
68. Agency on Energy Efficiency and Energy Saving of Ukraine. Available online: <http://saee.gov.ua/en> (accessed on 26 June 2019).
69. Complex Study of Results and Economic Efficiency of the State Program of Energy Efficiency and Development Sphere of Production of Energy with Restored Source of Energy and Alternative Fuels for 2010–2020 Years by Results of Examination of Participants in 2016–2017. Available online: <http://saee.gov.ua/sites/default/files/Ocinka.pdf> (accessed on 26 June 2019). (In Ukrainian)

© 2019 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<http://creativecommons.org/licenses/by/4.0/>).