Energy Consumption in Assessment of Shadow Economy

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Abstract

The article deals with study of the relationship between energy consumption and the level of the shadow economy. Based on the comparison of average rates of renewable energy consumption and the shadow economy per capita of EU countries and Ukraine for the period 2005–2016, the authors distinguish clusters of countries by the nature and direction of the relationship between the analyzed indices. The study of these relationships is based on the linear relationship concept between the shadow economy and energy consumption. The EU countries and Ukraine are identified as the statistical base of the study and the assessment period is 2005–2016. The results confirm the hypothesis of the shadow economic activity impact on energy consumption and prove their dependence on the scientific and technological progress in the country. All indices are statistically significant at the level of 1% and 5% and 10% respectively. This research let the authors conclude that it is necessary to take into account the energy consumption volumes in the process of estimating the shadow economy under the influence of innovative technologies and processes. Empirical calculations have proved the high level of the shadow economy in the vast majority of European Union countries, the average value of which is 22%.

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1. Introduction

The transition from extensive and intensive types of management to environmentally friendly type contributes to the rationalization of the non-renewable resources use and efficient implementation of renewable natural resources, to the improvement of the environment and the reduction of its destructive impact, which in turn provides an increase in macroeconomic indices. The above mentioned necessitates the transformation of the public administration mechanisms, considering the sustainable development concept, the efficiency of implementation and use of which depends, first of all, on the effectiveness of the implementation of its individual components. Thus, according to the “World Sustainable Development Goals 2016-2030”, declared as one of the key directions of the country's development is to provide access to inexpensive, reliable, sustainable, and modern energy sources, including by increasing the renewable energy sources share in the energy market and reducing energy consumption in general. The successful implementation of these measures is possible only due to the dual nature of energy consumption.

Nowadays, energy security issues are among the most pressing and investigational problems in the world. The roadmap for implementing energy-saving reforms is the Energy Roadmap 2050 adopted by the European Commission in 2012, which sets out the key principles for transforming the functioning of the energy market in the world. Thus, according to the EU Energy Efficiency Directive 2012/27 / EU, the main target for 2020 is to reduce energy use by 20% and to increase energy efficiency by 32.5% by 2030.

Given these facts, the governments of the vast majority of EU countries have identified their own National energy efficiency targets for 2020 and have developed national strategies to achieve them. In general, according to the results of 2016, the vast majority of EU countries have substantially reduced their energy consumption and practically come close to their targets. In France and Germany, the real energy consumption is almost 20 million tons higher than the planned ones, while in Romania it is even 12 million tons lower (EU 2020 targets, 2019).

On the one hand, energy resources are used by representatives of the official sector of the economy in order to increase production volumes, improving the economic development indices of the individual entity and the country as a whole. The above-mentioned leads to a significant increase in volume of global energy consumption. Thus, according to the International Energy Agency (IEA, 2021), energy consumption increased from 18231.0 TWh in 2007 to 23696.0 TWh in 2017 (29.9%), which is 2.7 MWh per capita and 3.2 MWh per capita, respectively. The same situation is observed in terms of the world volume of natural gas final consumption, which increased by 20% over the same period (from 58248075.0 TJ to 69888762.0 TJ).

The share of non-renewable energy consumption in the period 2007-2017 decreased by only 1.1% and made up 82% of the total final energy consumption in 2017. At the same time, according to the World Bank (2021), annual GDP growth rates are much lower over the same period. Thus, in 2017 the GDP growth rate was 3.1%, for the period 2007-2017 it averaged 2.45%.

On the other hand, a large share of energy resources is used in the informal sector of the economy as a basis for producing goods or for providing services. Despite a number of regulations in the energy-saving field, strengthening of control over the energy resources market, stimulation and financing of measures for the energy-saving technologies implementation, a significant part of the shadow energy market, which is not controlled and managed by the state, is peculiar for most countries. To date, the share of the shadow economy fluctuates within 10-40% of GDP (World Bank, 2021). In advanced economies the level of shadow economy is 10-20% of GDP, in emerging economies - 30-35 percent of GDP, in CIS countries these values exceed 40% (World Bank, 2021). According to the United Nations Office on Drugs and Crime (2018), 2 to 5% of the world GDP is formed in the shadow economy.

Given that the production of most goods and services in the shadow economy is impossible without the use of natural resources, including energy, it would be appropriate to analyze the statistical significance between energy consumption and the level of the shadow economy.

It should be noted that our previous studies focus mainly on a more general analysis of indicators of sustainable development of individual countries in the context of energy, water, forest, land resources, determining the main determinants of its achievement. The analysis concludes that the level of shadowing of the economy has a negative impact on GDP to carbon dioxide emissions, the amount of budget expenditures for environmental protection and the volume of environmental payments, and therefore has a destructive effect on achieving sustainable development goals.

At the same time, a considerable amount of our work is devoted to the study of the shadow economy and its impact on the indicators of economic and environmental development of both Ukraine and EU countries, the analysis of existing models of assessing the level of the shadow economy.

The aim of this article is to investigate the link between energy consumption and the level of the shadow economy in Ukraine and the EU countries based on the hypothesis about the linear relationship between shadow economic growth and environmental pollution, to develop and approve an approach to assessing the level of shadowing of the economy using the energy consumption method.

The paper is structured in the following way: Section 2 presents the literature review on the subject and formulation of the hypothesis of the paper; Section 3 provides the methods applied in the study; in Section 4 the results of calculations are discussed; in Section 5 concludes.

2. Literature Review

The concept of “informality” was first formed in 1971 in the territories of the African continent: in Ghana, with the introduction of Kate Hart by the concept of “informal income opportunities” and in Kenya by the International Labor Organization, which first introduced the terms “inform-al” economy “and “informal sector”.

According to the concept of K. Hart (1973), the difference between the income generated in the formal and informal sectors of the economy is equal to the difference between the officially declared level of wages and income from self-employment.

To date, there are two approaches to understanding the shadow economy in the scientific literature: the behavioral approach and the definitional approach. According to the first approach, shadow economic activity is considered as any unregistered economic activity. Representatives of this approach define shading as an economic sector in which both legal and illegal production of goods, works, and services that are not reflected in official estimates are carried out. The behavioral approach is to analyze the patterns of behavior of buyers and sellers - participants in the unofficial market based on a comparison of risks and costs that arise in the process of state control over the shadow activity in the country. The main provisions of the definitional approach were the assertion that the motivator for the offender's actions is the desire to maximize their income.

By the nature of illicit financial flows, there are two approaches to understanding them: the shadow economy as a result of deliberate actions by economic agents and as a consequence of unintentional errors and miscalculations. Edgar L. Feige (1977) defines the shadow economy as economic activities and income derived from evasion of government regulation, taxation or surveillance; a conscious circumvention of the specific set of rules set out by the economic participants.

Thus, the analysis showed a significant differentiation of approaches to the concept of shadow economy, the content of which depends on the goals and the level of research (the systematization of approaches is given in Table 1).

Table 1. Summary of the empirical literature on essence of shadow economy

Theory	Author	The essence of the shadow economy
The theory of anomie 1897-1949	E. Durkheim (1993) R. Merton (1996)	The reaction of members of society to the excessive pressure from external institutions, actions, norms of behavior adopted in society, which is manifested not perception of generally accepted norms in civil society
The theory of modernization 1959-1969	A. Lewis (1982)	The result of a quasi-evolutionary process characterized by the absence of positive economic change in the country.
The theory of rational crime 1960-1968	G. S. Becker (1968)	As a result of violation of the optimal ratio of probability of economic offense and punishment of the offender for these actions
Behavioral theory 1968-1995	G. J. Stigler (1974), M. Friedman (1984)	Analyzing the behaviors of buyers and sellers of the unofficial market which based on a comparison of the magnitude of risk and profitability of transactions
Addiction theory 1973-1981	K. Hart (1973)	A tool for providing livelihoods for economically disadvantaged people
Neoliberal theory 1989-2005	H. De Soto (1989)	Forced actions of economic entities, aimed at saving time, money and effort, caused by imperfect state policy and the complexity of the stated procedures of doing business activity
Definitional approach 1992-2000	L. Medina și F. Schneider (2018)	Sector of economy in which both legal and illegal production of goods, works, services not reflected in official GDP estimates is carried out
The theory of tax morality 2007-2014	C. Williams (2006)	The consequence of low moral values of the population

Source: Authors own compilation

However, the implementation of an effective policy of de-shadowing the economy depends on the completeness and soundness of the study of the concept and requires a unified approach. Today, there is a considerable variety of methods of estimating the shadow economy, the systematization of which is carried out in Table 2.

Table 2. Analysis of methods of estimation of volumes of shadowing of economy

Method	Methodology	Features of application
Method of residues	SE = ΔD + FI – CA – ΔR	Change in external debt (ΔD), net foreign direct investment (FI), balance of payments deficit (CA), foreign exchange reserves (ΔR)
Dooley's method	SE = FB + FI – CA – R – EO – WBIMF – INTEAR/rus	External borrowing (FB), net foreign direct investment (FI), balance of payments deficit (CA), foreign exchange reserves (R), errors and omissions (EO), difference in external borrowing from IMF and World Bank reports (WBIMF), interest income (INTEAR), the rate on foreign currency deposits in USD (INTEAR /rus)
Foreign trade error method	$SE = PX - (X \times CIF) + IM - -(PM \times CIF)$	Import Costs by Importing Country Reports (PX), Country Export Cost (X), Insurance & Freight Cost (CIF), Import Cost (IM), Export Cost (PM)
The method of speculative capital	SE = SK + EO	Total short-term capital (SK), errors and omissions (EO)
World Bank Method	SE = CDET + NFI - CAD - CRES	Changes in total external debt (CDET), net foreign direct investment (NFI), balance of payments deficits (CAD), accumulated foreign exchange reserves (CRES)
The Currency Demand Approach	$SE^t = W^t\left[f^t_{(t_0)} - 1\right] = W^t\left[\frac{C^t D^{t_0}}{C^{t_0} D^t} - 1\right] = = W^t\left[\frac{C^t D^{t_0} - C^{t_0} D^t}{C^{t_0} D^t}\right]$	Official GDP in t-year (W^t), change in the ratio of cash to deposits in the settlement period relative to the base ($f^t_{(t_0)}$), cash in the t-th and base t_0-th periods (C^t, C^{t_0}), deposits with banks in the t-th and base t_0-th periods (D^t, D^{t_0})
The Transactions Approach	$SE^t = W^t\left[\frac{\varpi^t C^t D^{t_0} - C^{t_0} D^t}{C^{t_0} D^t}\right]$	Coefficient of increase in money turnover in the shadow sector in the t-year compared to the official sector (ω^t), cash in the t-th and base t_0-th periods (C^t, C^{t_0}), deposits with banks in the t-th and base t_0-th periods (D^t, D^{t_0})
MIMIC-model	$Y_1 = \lambda_1\eta + u_1,$ $Y_2 = \lambda_2\eta + u_2, \ldots,$ $Y_q = \lambda_q + u_q,$ $\eta = \gamma_1 x_1 + \gamma_2 x_2 + \gamma_3 x_3 + \ldots + \gamma_p x_p + \nu$	Observed explanatory indicators of the shadow economy ($Y_q, q = \overline{1,n}$), latent variable (η), latent variable (u_q), estimates for model structural parameters (λ_q), observed factors ($x_m, m = \overline{1, p}$), structural parameters of model (γ_m), deviation term (ν)

Source: generalized based on (Hart, 1973; Feige, 1977; Gutmann, 1977; Dell'Anno *et al*., 1977; Medina and Schneider, 2018; Remeikienė *et al*., 2018)]

Most scientists believe that the methods listed in Table 2 have significant disadvantages. They require a large amount of data; their calculation is very time consuming and the reliability of the received results for some of them is low. At the same time, a significant number of scientists are considering energy consumption methods as those that provide high reliability of the results obtained at the same time of little time.

They try to find the causality between economic growth and energy consumption and develop an approach to assessing the level of shadowing of the economy precisely through the volume of energy consumption. There is extensive empirical literature on energy consumption and its relations with various major economic variables and economic growth (Masharsky *et al*., 2018; Brychko *et al*., 2021; Lyeonov *et al*., 2021; Lyulyov *et al*., 2021; Skare and Porada-Rochoń, 2019; Vasylieva *et al*., 2017), GDP and income (Cebula and

Pimonenko, 2015; Samusevych *et al*., 2021; Vysochyna *et al*., 2020; Štreimikienė *et al*., 2021), investment development (Chygryn and Krasniak, 2015; Formankovaa *et al.*, 2018), sustainable development and climate change (Kasych and Vochozka, 2017; Us *et al*., 2021; Li *et al*., 2018; Stankuniene, 2021), social development (Lyeonov and Liuta, 2016; Didenko *et al.*, 2020; Lyeonov *et al*., 2020; Kosach *et al*., 2020).

There is a group of authors who confirm the existence of bi-directional causality, while a considerable number of scientists deny that there is a causal link between energy consumption and economic growth. Soytas and Sari (2003) argued that there was a bilateral causality for Argentina. Similar evidence has been found for EU countries (Istudor *et al*., 2021), Lithuania (Rahman *et al*., 2020), Balkan Countries (Mitić *et al*., 2020), Croatia (Jakovac *et al.,* 2021), OECD countries (Skvarciany *et al.*, 2021; Androniceanu *et al*., 2020), Russian regions (Davidson *et al*., 2021), V4 countries (Chovancová and Tej, 2020), Visegrad countries (Štreimikienė, 2021).

As a rule, the vast majority of works (Mishchuk *et al.*, 2020; Shpak *et al*., 2021; Kravchenko *et al.*, 2021; Stroińska, 2020) is devoted to the analysis of the link between energy and the official sector of the economy. For example, Karanfil (2008) investigated the relationship between energy consumption from different sources and gross domestic product, on the example of Bulgaria, Poland, Romania, Hungary and Turkey over the period 1980 - 2012/2013. In order to improve the reliability of the obtained results, the author applies a dual approach - long and short-run bidirectional relationships and three-stage analysis: tests of stationarity, cointegration and causality are considered. The analysis concludes that there is multidirectional communication for different countries of the world.

At the same time, there are a considerable number of scientists who have been researching the main determinants of the shadow economy (Yarovenko, 2021; Kobushko *et al.*, 2021; Kuzmenko *et al.*, 2020; Leonov *et al.*, 2019). Kaufman and Kaliberda (1996) suggest the hypothesize that the increase in total electricity consumption is an index of the total (official and informal) GDP growth. Having this proxy index for the whole economy and then subtracting the official GDP estimate from this dimension, Kaufmann and Kaliberda obtain an assessment of informal GDP.

Karanfil and Ozkay (2007) used an environmental method to estimate the level of the shadow economy in Turkey, which is based on the link between energy consumption, economic growth and carbon dioxide (CO2) emissions. The authors performed their results on the basis of statistical data for the period 1973 - 2003. According to the results of the analysis, the authors proved that the volume of real GDP, given the shadow economy, is much higher than declared. However, in his work Karanfil (2008) conducted a more detailed analysis of the relationship between these indices in the long and short term period 1970–2005. The author concludes that there is a statistically significant unidirectional cause-and-effect relationship between GDP and short-term energy consumption and its absence in the long-term.

Basbay *et al.* (2016) examined the relationship between energy consumption and the shadow economy for a group of 159 countries over the period 1980–2012. Their results indicate a negative relationship between indicators. For example, developing countries found an average reduction in energy intensity of approximately 0.13% due to the increase of informal sector by 1 %.

Elgin and Oztunali (2014) at first confirmed a non-linear relationship between the indices for some countries of the world and then for Turkey. In particular, 31 countries (over 40% of the list) with very high levels and 35 countries (less than 20%) with very low levels of shadow economy have a strong statistically significant correlation with energy consumption. While in countries with medium shadow economy (20-40%), this relationship is much smaller. For the G20 and for countries with a shadow economy level of less than 20% of GDP, this relationship is asymmetric.

Dunkerley (1982), Ebohon (1996), Templet (1999) argue that the necessary condition for social, economic, and technological progress is energy use. According to the authors' beliefs, energy is the main source and decisive force in the economic development of the country.

The main electricity consumption methods that are the basis for assessing the level of shadow economy include:

The Kaufmann - Kaliberda Method. The main hypothesis of this method is the assumption that the growth of electricity consumption indicates an increase in total GDP, which is formed by the performance of economic entities in both the official and shadow sectors of the economy. The level of the shadow economy is calculated as the difference between the proxy indicator of the elasticity of electricity consumption for the general economy and the total measurement of official GDP estimates.

The Lacky Method assumes that much of the shadow activity in the country is carried out by households and is therefore related to energy consumption. Thus, estimating GDP per unit of electricity produced in the shadow economy allows the author to estimate the level of shadow economy in the countries.

These methods are quite simple and do not require a large amount of data. At the same time, their main disadvantages include the lack of consideration by the authors of the impact of scientific and technological progress on energy consumption in the economy and the existence of significant differences in energy consumption in different countries of the world, which is subject to the use of one country for the rest of the sample (Lacko's method uses the shadow economy of the United States as a base) the reliability of the results is significantly reduced.

3. Materials and Methods

The hypothesis of the link between the shadow economy and energy consumption was tested in the following logical sequence: in the first stage, we will analyze the availability and nature of the relationship between energy consumption and the level of the shadow economy. To this end, the authors will use the function of dependence, which is based on the hypothesis that the energy consumption amount is determined by two components of economic development: formal and informal. We will use GDP per capita as an index of the official economy. The informal sector index is the share of shadow economy in total GDP. The study is based on a modified model of economic growth, which has the following form:

$$E = F(Y, Y2) \tag{1}$$

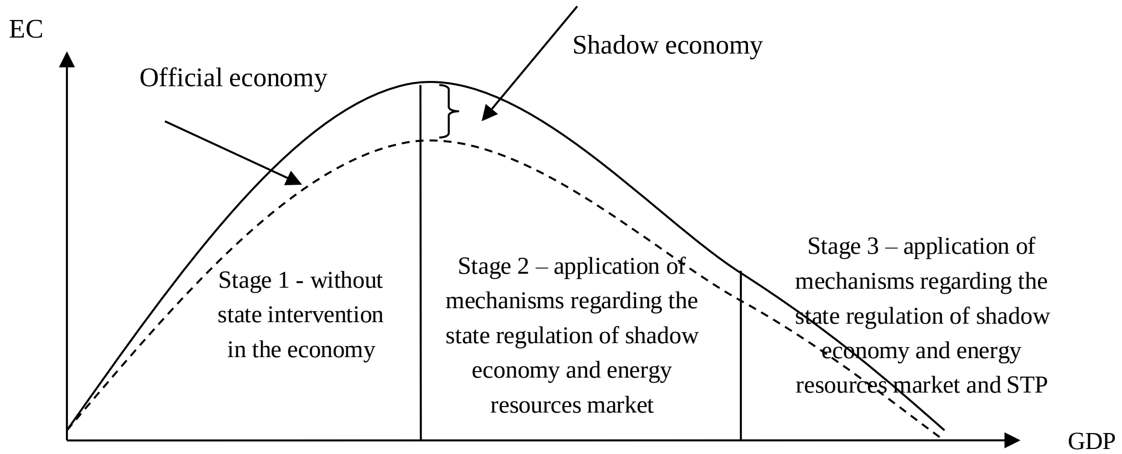
Y – gross domestic product;

Y2 – share of shadow economy in total GDP;

The study of the level of the shadow economy by the electric method is to compare the growth of domestic electricity consumption with the growth of GDP. At the same time, it is assumed that the increase in internal electricity consumption should correspond to the growth of real GDP. If there is an excess of growth in domestic electricity consumption over GDP growth, then it is considered that electricity is directed to production in the shadow economy. Figure 2 shows the features of the ratio of the shadow and official sectors of the economy to energy consumption, depending on the level of state regulation in the country and its economic development.

This assumption is correct if the technological level of production of goods, performance of works and provision of services remains unchanged. In the case of investing in energy-efficient projects and energy-saving measures, the difference between the index of change in internal electricity consumption and the index of change in GDP increases as a result of scientific and technological progress (Figure 1).

Figure 1. Ratio of the shadow economy and energy consumption by the country's development stages



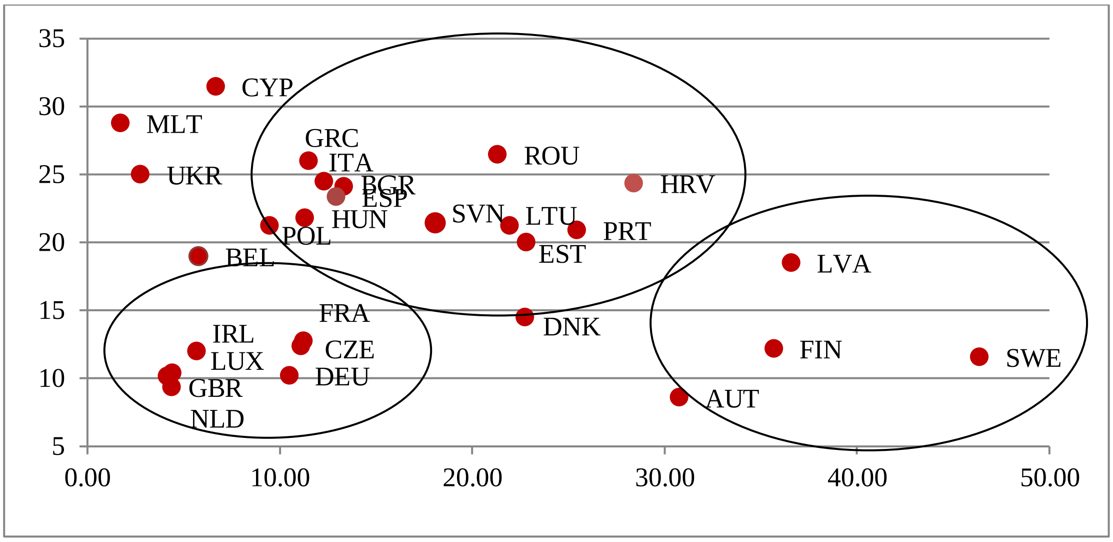
Source: Authors own compilation

The calculations will be based on data from the World Bank (2021) and the European Commission (2021).

4. Results

At the initial stage, we will analyze the trends of factor and result indices. Average rates of energy consumption over the period 2005–2016 are shown in Figure 2 as the analysis for the given period shows. Comparison of average rates of renewable energy consumption and shadow economy during 2005-2016 indicates that there is a non-linear relationship between them. Thus, one can distinguish a group of countries characterized by a direct correlation between the shadow economy and energy consumption (Ireland, Luxembourg and Netherlands) and those countries where a higher value of the shadow economy is accompanied by low energy consumption. However, for the vast majority of countries, there is a direct correlation between the analyzed indices.

Figure 2. Average rates of renewable energy consumption per capita and shadow economy per capita among EU 2005–2020 years



Note: AUT –, BEL – Belgium, BGR – Bulgaria, CYP – Cyprus, CZE - Czech Republic, DEU – Germany, DNK – Denmark, ESP – Spain, EST – Estonia, FIN – Finland, FRA – France, GBR - United Kingdom, GRC – Greece, HRV – Croatia, HUN – Hungary, IRL – Ireland, ITA – Italy, LTU – Lithuania, LUX – Luxembourg, LVA – Latvia, MLT – Malta, NLD – Netherlands, POL – Poland, PRT – Portugal, ROU – Romania, SVN – Slovenia, SWE – Sweden, UKR – Ukraine

Source: Authors own compilation

Thus, for Cyprus, Malta and Ukraine, the high level of shadowing of the economy (more than 25%) is accompanied by a low volume of renewable energy sources per capita (less than 10%). This indicates a high volume of use of non-renewable energy sources with a correspondingly high environmental burden. At the same time, a considerable number of countries (Latvia, Finland, Austria, Sweden) are characterized by rather high average rates of renewable energy consumption per capita with low levels of shadow economy. On the one hand, this situation may be conditioned by the high level of economic development of the country and, accordingly, by the existence of an effective state environmental and economic policy. On the other hand, we can assume that there is a direct link between shadow financial transactions and the use of renewable energy.

In order to verify the stationary data, the values of all economic variables were converted to logarithmic values. The results of the Dickey-Fuller (ADF) and Phillips Perron (PP), Breitung unit-root test and LLS test are presented in Table 3, showing that in terms of energy consumption, shadow economy and gross domestic products ports there was no stationarity. The absolute value of their test statistics was less than the absolute value of 5% of the critical value. However, the first differences of the series (Table 3) were fixed, which means that they are all integrated degree 1 (I (1)). Energy consumption and shadow economy were fixed at the data level (I (0)). It indicated that automatic regression distributed lag is an appropriate method of analyzing long-term relationships between series. Therefore, an ARDL-related approach is used for this study.

The test results of the Augmented Dickey-Fuller (ADF) and Phillips Perron (PP) tests demonstrated in Table 3 prove the non-stationary of all of the analyzed data for all EU countries and Ukraine. The absolute value of their test statistics was more than the absolute value of their critical value. For example, the value of the ADF test statistic for lnSE for Austria is -1.993 is less than the critical value for sample less than 25, which is -2.66 and indicates the non-stationarity of the data analyzed. Similar results were obtained for all countries and indicators. For the indicators of the level of shadowing of the economy, energy consumption and GDP, the obtained values are less than critical. The results of the Breitung unit-root test show that all the analyzed data is first-order integrated. The results of the analysis allow us to reject the unit root null hypothesis for all indicators within all countries at the 1% level of significance.

Table 3. Unit root tests at the levels of the variables.

Variables	ADF Test Statistics	Philips Perron Test Statistics	LLS test	Breitung unit-root test
Austria				
Ln EC	-2.513	-2.181	-2.179	-1.793
Ln SE	-1.994	-2.433	-0.234	-1.472
Ln GDP	-0.659	-1.256	-1.659	-1.106
Belgium				
Ln EC	-2.569	-2.387	-1.986	-1.582
Ln SE	-1.720	-1.781	-1.444	-0.816
Ln GDP	-1.259	-1.698	-1.988	-0.646
Bulgaria				
Ln EC	-0.439	-0.249	-0.986	-1.415
Ln SE	-2.479	-3.178	-3.208	-3.536
Ln GDP	-2.159	-1.879	-2.199	-2.699
Cyprus				
Ln EC	-1.527	-2.052	-2.659	-2.739
Ln SE	-1.141	-1.261	-2.368	-2.568
Ln GDP	-1.898	-3.699	-3.855	-2.488
Ukraine				
Ln EC	-2.146	-2.815	-1.239	-4.473
Ln SE	-2.326	-1.568	-2.666	-1.366
Ln GDP	-1.458	-1.656	-1.879	-1.258

Source: Authors own calculation

The co-integration among the series was tested using an attached test approach. According to the obtained results, the value of F-statistics for Ukraine and EU countries is less than the F-critical value by 1%, 5% and 10% respectively. Thus, one can conclude that there are no long-term relationships between the variables.

In order to verify the validity of these results, we will evaluate the cointegration of the analyzed data using Johansen tests. As shown by the results in Table 4, for all the analyzed countries, the obtained values are more the critical values and allow to accept the hypothesis of cointegration of the analyzed data series. Confirmation of the hypothesis about the cointegration of the analyzed data allows us to conclude that there is a dependence between them and the correlation of their change. If the relationship between GDP and energy consumption can be explained by the direct correlation between production volumes and energy consumption, then the existence of a link between this indicator and the level of shadowing of the economy suggests that it can be used as an indicator of shadow production and provision of services.

Table 4. Johansen tests for cointegration (fragment)

Country	Rank	Trace statistic	5% critical value	Country	Rank	Trace statistic	5% critical value	Country	Rank	Trace statistic	5% critical value
AUT	0	35.18	29.69	*HUN*	0	50.11	29.69	*ESP*	0	58.38	29.69
	1	20.47	15.41		1	20.59	15.41		1	32.12	15.41
	2	3.81	3.76		2	4.04	3.76		2	4.66	3.76
BEL	0	38.19	29.69	*IRL*	0	39.19	29.69	*EST*	0	44.43	29.69
	1	19.43	15.41		1	16.51	15.41		1	20.41	15.41
	2	4.02	3.76		2	3.90	3.76		2	4.05	3.76
BGR	0	45.02	29.69	*ITA*	0	43.90	29.69	*FIN*	0	68.85	29.69
	1	39.44	15.41		1	32.84	15.41		1	37.34	15.41
	2	4.73	3.76		2	3.94	3.76		2	5.41	3.76
CYP	0	37.29	29.69	*LTU*	0	68.05	29.69	*FRA*	0	31.61	29.69
	1	16.98	15.41		1	23.69	15.41		1	17.08	15.41
	2	5.17	3.76		2	10.84	3.76		2	3.83	3.76
CZE	0	54.20	29.69	*LUX*	0	59.93	29.69	*GBR*	0	121.88	29.69
	1	16.48	15.41		1	37.36	15.41		1	89.22	15.41
	2	4.14	3.76		2	5.79	3.76		2	-	3.76
DEU	0	77.73	29.69	*LVA*	0	47.19	29.69	*GRC*	0	59.07	29.69
	1	45.24	15.41		1	29.99	15.41		1	36.54	15.41
	2	3.88	3.76		2	7.21	3.76		2	4.60	3.76
DNK	0	53.22	29.69	*MLT*	0	59.09	29.69	*HRV*	0	54.83	29.69
	1	26.52	15.41		1	47.43	15.41		1	17.56	15.41
	2	4.72	3.76		2	14.41	3.76		2	3.96	3.76

Source: Authors own calculation

Long-term and short-term relationships are tested using the Breusch-Godfrey Serial Correlation LM Test. The expediency of its application is explained by the fact that it allows to determine the autocorrelation of any order, is suitable for use for both cointegrated and non-integrated data series, and therefore its application will allow us to check the validity of previous results.

The results of the LM testing of Breish-Godfrey (Table 5) indicate no serial autocorrelation. In addition, the heterostatic diagnostic test also revealed a correlation between the analyzed indices in the short run and its absence in the long run.

Thus, we can conclude that there is a short-term relationship between the level of shadow economy and energy consumption. On the one hand, the results are in line with the specificities of energy use in the country - production of goods in the shadow economy is directly related to energy use in the current rather than the long term.

At the same time, these results indicate that there is no effective policy to counteract the shadowing of the economy and the country's transition to renewable energy.

Table 5. Breusch-Godfrey Serial Correlation LM Test.

Country	lags p)	chi2	df	Prob>chi2
Austria	lag(1)	17.27	1	0.0000
	lag(8)	26.48	8	0.0000
Belgium	lag(1)	14.33	1	0.0000
	lag(8)	19.89	8	0.0000
Bulgaria	lag(1)	21.38	1	0.0000
	lag(8)	26.18	8	0.0000
Cyprus	lag(1)	24.38	1	0.0000
	lag(8)	29.57	8	0.0000
Czech Republic	lag(1)	17.28	1	0.0000
	lag(8)	31.31	8	0.0000
Germany	lag(1)	17.00	1	0.0000
	lag(8)	18.29	8	0.0000
Denmark	lag(1)	27.39	1	0.0000
	lag(8)	29.84	8	0.0000
Spain	lag(1)	31.08	1	0.0000
	lag(8)	36.25	8	0.0000
Estonia	lag(1)	25.12	1	0.0000
	lag(8)	27.92	8	0.0000
Finland	lag(1)	12.17	1	0.0000
	lag(8)	23.39	8	0.0000
France	lag(1)	25.32	1	0.0000
	lag(8)	34.90	8	0.0000
United Kingdom	lag(1)	18.00	1	0.0000
	lag(8)	26.61	8	0.0000
Greece	lag(1)	24.31	1	0.0000
	lag(8)	29.07	8	0.0000
Croatia	lag(1)	18.51	1	0.0000
	lag(8)	22.05	8	0.0000
Hungary	lag(1)	29.29	1	0.0000
	lag(8)	31.57	8	0.0000

Source: Authors own calculation

Given the statistically significant relationship between the analyzed indices, we estimate the level of the energy consumption in shadow economy by the following formula:

$$\mathrm{EC}_{\mathrm{SE}} = \frac{\frac{\mathrm{EC}_1}{\mathrm{EC}_0} - \left(\frac{\mathrm{G}DP_1}{\mathrm{G}DP_0} + \lambda\right)}{\frac{\mathrm{G}DP_1}{\mathrm{G}DP_0}} \tag{3}$$

where EC_1 - the volume of internal electricity consumption in the reporting period;

EC_0 - the volume of internal electricity consumption in the same previous period;

λ - the difference between the adjusted index of change and the change consumption index of the fuel, heat, and electricity in the base period (the share of energy-saving technologies and the results of scientific and technological progress in the production process).

The results of the calculations in Table 6 show a sufficiently high level of the energy consumption in shadow economy in the vast majority of European Union countries. These values can be considered as indicators of the level of the shadow economy in the country. Ukraine, as the only non-EU country, has the highest rates in the unofficial sector of the economy, which are at the level of 35-40%. At the same time, Germany (8-9%), Netherlands (8.7-9%) and Austria (11-12%) have the lowest level of the shadow economy.

At the same time, practically all the analyzed indicators show a slight decrease in the level of shadowing of the economy for the period 2013-2016. This situation may be conditioned by the active implementation at both international and national level of a number of legislative and organizational measures aimed at the de-shadowing of the economy. The largest reduction in the level of energy consumption in the shadow economy occurred in Ukraine. This is due to the adoption of a number of regulations aimed at the de-shadowing of the economy and the introduction of anti-corruption policies. At the same time, the reduction of shadow energy consumption is insignificant and ranges between 1-5%. This may be due to a number of objective reasons, which are only partially related to the de-shadowing the economy. That is why the object of further research may be the analysis of the influence of explicit and latent factors on the level of shadow energy consumption.

The results for most countries of the world are consistent with previous research findings conducted by Medina, Schneider, Kelmanson, Kirabaeva, Medina, Mircheva and Weiss. Based on the analysis, we can conclude that for some countries such as Austria, Czech Republic, Denmark, Spain, Estonia, Finland, France, United Kingdom, Greece, Croatia, Ireland, Italy, Luxembourg, Portugal, Ukraine the level of shadowing of the economy, calculated by the method of energy consumption, significantly exceeds the results based on the MIMIC approach while for Lithuania, Latvia, Sweden the values are significantly lower.

One of the reasons for this situation is the presence of a significant proportion of the shadow economy at the household level, which is not taken into account by these survey methods. At the same time, we believe that the method of energy consumption, unlike other methods, involves a more comprehensive account of the shadow financial flows, since it does not depend on the totality of indicators of economic development of the country and the fullness of their coverage.

Table 6. The level of energy consumption in shadow economy of the EU countries and Ukraine

Country	2013	2014	2015	2016	Country	2013	2014	2015	2016
Austria	11.15	11.52	11.13	11.95	Hungary	23.74	23.06	22.16	21.85
Belgium	18.76	19.31	18.54	18.27	Ireland	18.88	18.45	16.45	15.87
Bulgaria	30.24	30.58	29.53	28.48	Italy	43.03	41.28	41.01	38.72
Cyprus	34.88	36.29	34.22	33.71	Lithuania	19.62	18.58	17.89	18.94
Czech Republic	14.48	14.84	13.55	13.18	Luxembourg	13.13	12.94	12.63	12.62
Germany	9.97	10.39	9.21	8.73	Latvia	19.27	18.56	17.71	18.49
Denmark	20.54	20.22	18.75	19.51	Malta	35.91	35.78	37.01	38.78
Spain	38.32	38.75	38.26	35.02	Netherlands	9.03	9.40	9.74	8.72
Estonia	28.73	28.15	27.45	28.96	Poland	25.40	25.16	24.13	22.24
Finland	20.85	21.66	20.08	22.03	Portugal	26.99	27.18	25.72	23.76
France	15.08	15.49	15.13	14.53	Romania	33.52	31.96	30.31	30.59
United Kingdom	13.14	12.69	11.68	11.03	Slovenia	25.53	25.67	23.96	22.53
Greece	34.52	33.78	32.97	32.16	Sweden	13.63	14.11	13.62	13.46
Croatia	27.87	27.89	27.01	25.34	Ukraine	40.14	41.28	36.70	35.55

Source: Authors own calculation

5. Conclusions

The modern trends of Ukrainian economy development are characterized by instability of economic activity indices, low efficiency of economic, political and social reforms, the increase of the level of enterprises' loss, corruption, etc. The transformations in the world are influenced by a large number of exogenous and endogenous factors that stimulate these processes on the one hand and exacerbate economic imbalances in the country, on the other. One of the most influential factors today is the shadow economy. Mostly the financial flows are often the objects of manipulation while preparing the statistical, accounting and tax reporting, determining the performance of economic agents, and as a result significantly impede investment processes in the country, limit the pace of economic development and significantly reduce the effectiveness of implemented reforms. Given the importance of the managerial component in ensuring the effectiveness of the shadow economy in the country, a prerequisite for the development and implementation of public policy measures in this area is the availability of a complete and reliable assessment.

The study shows that there is a statistically significant correlation between the shadow economy level and the energy consumption volume for the vast majority of EU countries. Considering the important role of energy resources in the production process, including in the informal sector of the economy, the correlation between them indicates, on the one hand, the relationship between the economic and environmental development of the country, and on the other hand, can serve as a tool indirectly assessing the level of the shadow economy. Based on the put forward hypothesis, an approach was proposed to estimate the level of the shadow economy, based on the consideration of the relationship between shading, energy consumption and the level of scientific and technological progress in the country.

Thus, the results of the analysis indicate the necessity to take into account the energy component in the process of developing a methodological toolkit for de-shadowing the economy minus factors (one of which is the level of NPT) that can significantly distort the results of the assessment.

Despite the current limitation of the sample size through the analysis of correlation between shadow economy and only energy consumption and not gas, water consumption, that does not let to make general and fundamental conclusions. However, the reasons for the significant differences in the obtained results and the results of research conducted by scientists using other methods of assessing the level of shadowing of the economy are not analyzed in more detail.

Secondly, we do not consider the fact that for some factors an average correlation can be increasingly caused by the similarity of tendencies regarding the changes in these indicators, but not by the close relationship between them.

Our research confirms the validity of the existence of electricity consumption approach to the definition of the level of the shadow economy of the country. We agree with Lapinskiene *et al*. (2017), Basbay *et al.* (2016) that electricity consumption method is an effective tool for assessing the size of the shadow economy and allows a comprehensive assessment of its level.

The goal of further research may be to define the tightness and nature of the relationship between the shadow economy and the water and gas consumption and development of a universal approach to the estimation of the level of shadowing of the economy, based on taking into account the amount of shady use of natural resources, while levelling the synergy effect from the complex influences of the analyzed factors.

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