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The modeling and forecasting of fuel and energy resources usage in the context of the energy independence of Ukraine

Abstract: The article analyzes the structure of energy resources, as a result of which the reasons for their irrational use in the Ukrainian economy are revealed. It has been established that during 2014–2018 there was a decrease in demand for traditional types of fuel and energy resources (FER), except for coal. The components of the process of supply and consumption of fuel and energy resources have been formed and detailed, and an integrated approach to their rational use has been developed, which will reduce the loss of energy resources and increase their efficiency. The author's approach is used in the form of visualized schemes for organizing the process of the rational use of energy

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resources, which will contribute to the implementation of an effective energy saving policy of the state, ensuring the competitive advantages of domestic enterprises, increasing their competitiveness, improving the economic and energy security of Ukraine. The expediency of constructing deterministic economic models for providing the Ukrainian economy according to different (adaptive and multiplicative) convolutions was substantiated and proved, on the basis of which a forecast and assessment of the energy independence of the Ukrainian economy until 2035, taking into account fuel and energy resources, was proposed. Based on the calculations, it was established that the state of energy independence of Ukraine is insufficient.

KEYWORDS: energy independence, Ukraine, fuel and energy resources, model, approach, forecasting

Introduction

The energy independence of the state is one of the key tasks of many countries' economic policy, including Ukraine, on which the full functioning of the economy depends. An important indicator of energy independence is the provision of self produced fuel and energy resources (FER), which depends on the natural resource base. Without skillful and rational use of energy resources, the country's progress is not possible. Ukraine's economic growth largely depends on the influence of many factors that interact with each other, change in time and space, and are specific to each component of economic development. But at the same time the availability of FER determines the functioning of the economy as a whole. Ukraine is one of the energy-deficient countries. Producing about 3–3.5 million tons of oil and gas condensate and 20–21 billion m^3 of natural gas in recent years, the needs of oil consumption are met by various estimates up to 10%, and in natural gas – up to 25% (The State Statistics Committee of Ukraine). However, gas consumption exceeds the consumption of natural gas in many countries, including France, Italy and Japan. The main reason lies in the irrational consumption of energy resources by both the population and industry. A high degree of fixed assets physical depreciation and technological backwardness in the most energy-intensive industries, low level of energy efficient technologies introduction and equipment (in industry, among the population), high level of energy losses during their transmission and consumption, mismatch of tariffs and energy prices, led the country's energy sector to the impossibility of working effectively and performing its functions.

The inability of this area to flexibly and promptly respond to changes in the environment is becoming increasingly apparent. This issue is also relevant because the rational use of energy resources is a priority of national security. Based on the above, the development of an integrated approach and the development of theoretical foundations for building and formalizing deterministic economic models of providing Ukraine's economy with energy resources in the context of globalization is of particular importance in terms of their savings and requires in--depth study.

1. Literature review

Despite numerous studies by foreign and domestic scientists, the issue of security and the use of fuel and energy resources remains relevant and open, in particular: Matsumoto et al. (2018) in its work, states that it is vital for all countries of the European Union (EU) to ensure their energy security. This is relevant due to geopolitical considerations and ongoing reforms of energy markets. Radovanović et al. (2017) developed a methodology for measuring the Energy Security Index, which differs from the existing measurement methods precisely in that it includes environmental and social aspects. Bompard et al. (2017) proposes a system of methodologies for assessing the energy independence of the Baltic States, which takes three indicators into account: "adequacy", "security" and "economic factor". The proposed methodologies are used to assess the energy independence of the Baltic States in the current and future scenarios: medium-term (2020) and long-term (2030). Yemelyanov et al. (2019) and Andrusiv et al. (2020) prove that the economic consumption of the national economy directly depends on the efficient consumption of energy resources. The conditions under which economic growth is accompanied by a decrease in the level of the economy dependence on energy imports are modeled. Nyman (2018) argues that policies pursued in the name of energy security directly contribute to climate danger. Cantor et al. (2016) explores the question: Is there a trade-off between energy efficiency and economic growth. Scientists point out that these concepts are inseparable. Johansson & Thollander (2018) conducted their research at Swedish companies. It was found that with reduced consumption of energy resources, enterprises may have higher profitability, as reduced energy costs directly lead to increased profits. Sotnyk et al. (2020) substantiate the role of electric transport in strengthening national energy security through the transition to renewable energy technologies and reducing the use of fossil fuels. Burlov et al. (2021) substantiated the mathematical model of the region energy sector management, which was based on three main system-forming indicators of social, economic and environmental systems. Scientists from China Suo et al. (2021) proposed a model CN-EES, which is able to predict energy needs for different scenarios of economic development, reflecting the uncertainties generated by the long-term (2021–2050) planning period. In recent years, the security of the energy supply has become one of the most pressing policy issues for Central and Eastern Europe (Butler 2018). Incekara & Ogulata (2017) argue that energy resources and energy policy are the main factors determining the country's position in a globalized world. Ukrainian scientists (Kneysler et al. 2020; Zelinska et al. 2020) proposed models for providing the Ukrainian economy with energy resources, in particular electricity and natural gas. It was established that Ukraine's economy is characterized by a shortage of energy resources, which is covered by imports, obsolete and physically worn out means of production, imperfection of economic and financial mechanisms, which determines the low level of use of fuel and energy resources. At the same time, many scientists (Zablodska et al. 2020; Popadynets and Maksymiv 2016; Rohozian et al. 2017) pay attention to the relationship between a reliable energy supply policy and environmental security and sustainable development.

At the same time, substantiation of management decisions concerning the interests of the state, population, economic entities and fuel and energy complex in the field of energy policy and regulation requires the formation of a unified approach to FER assessment, which would allow for optimistic forecasts of individual determinants in the economy of Ukraine.

2. Methodology description

To achieve the goal of the study, the following research methods were used in the work: graphic – to build a structural and logical diagram of the mechanism for the formation and use of fuel and energy resources and visualized diagrams of an integrated approach to organizing the process of rational use of energy resources; an economic and mathematical method – for the construction and formalization of deterministic economic models for assessing according to certain criteria and functional characteristics of objects of all levels of energy security – national and regional economies, industries and enterprises; statistical – for processing economic information on fuel and energy resources; forecasting – to determine the development trend of fuel and energy resources for the energy independence of Ukraine; theoretical generalization – for a deeper study of the issue of the country's energy independence. We have proposed a structural and logical scheme of the mechanism of formation and use of energy resources (Fig. 1), as part of the organizational and economic mechanism of the national economy energy security and a set of stages of the national economy with energy resources and their consumption in social reproduction.

The mechanism of formation and consumption of primary fuel and energy resources characterizes two processes: 1) ensuring the economy of energy resources; 2) consumption of energy resources in public reproduction. Let's describe its components in more detail. Both of the presented processes, described by the given scheme, are characterized by the occurrence of FER losses (Zapuhlyak 2016). Regardless of the stage of the formation processes or use and the type of primary energy resources, their losses occur due to factors that are common to the entire system: technological level of production; investments; state regulation; legislative and regulatory environment; level of competition; inefficiency of organizational and legal forms of doing business; GDP structure; structure of FER consumer costs, etc. Thus, the problem of energy saving covers several main aspects: the growth of stocks and sources of energy resources; reliability of the energy supply; pricing policy in the energy market; legislative and regulatory framework governing economic relations in the field of the production and distribution of energy resources; efficiency of energy resources use; environmental protection. Reliability of the energy supply is achieved by maximizing the involvement of local energy sources; diversification of energy resources; reduction of the share of imported energy resources in total consumption; interspecific replacement in the structure of energy resources use; formation of long-term and reliable international partnerships in the field of supply and consumption of energy resources, etc. Energy
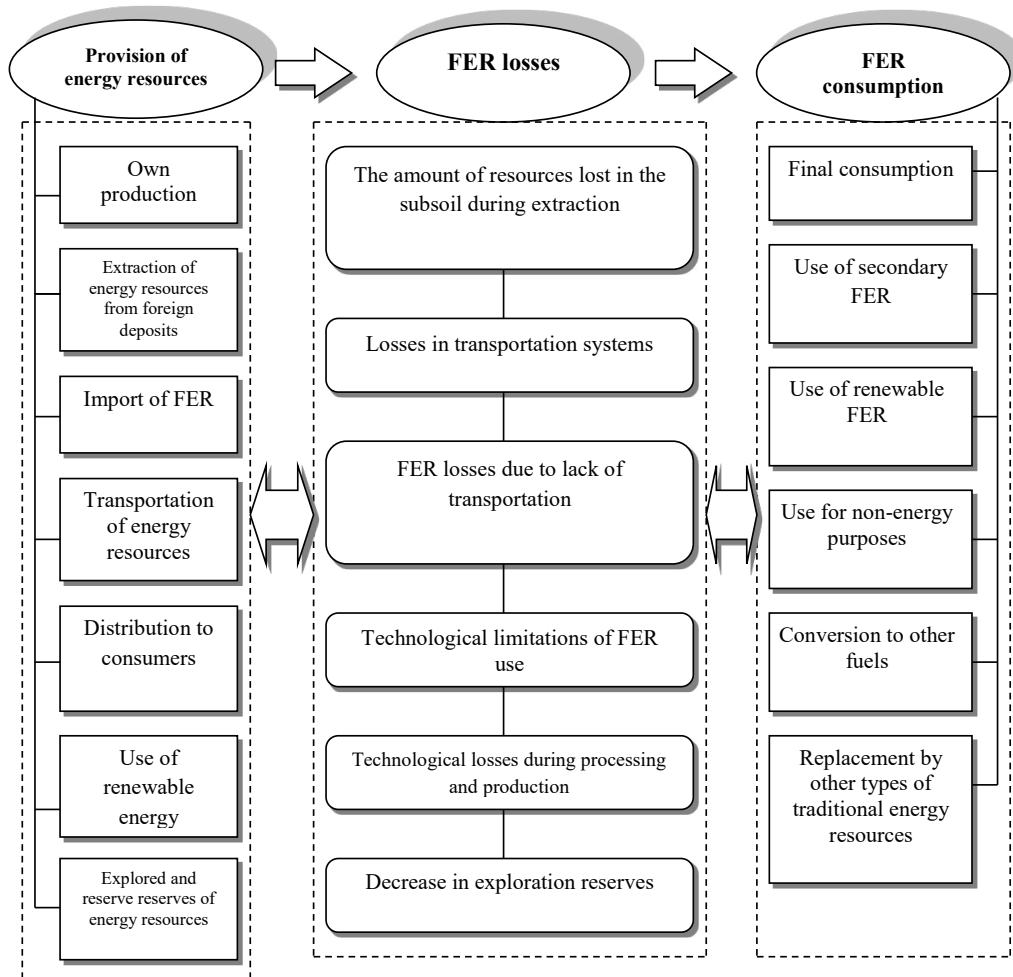
Fig. 1. Structural and logical scheme of the mechanism of formation mechanism and use of fuel and energy resources in Ukraine
Source: own study

Rys. 1. Schemat strukturalny i logiczny mechanizmu powstawania i wykorzystania paliw i surowców energetycznych na Ukrainie

pricing should be based on market principles, be transparent and understandable to all energy market participants.

At the same time, the price level should correspond to the real costs of production and the supply of energy resources, which will stimulate the completeness and timeliness of payments for consumed resources. Competition among suppliers and consumers in the energy markets will ensure the establishment of fair prices, which is possible by creating the conditions for free access for all the stakeholders (Popadynets et al. 2020) to the objects of transport energy

infrastructure (pipelines and electricity networks). Tariffs for the services of heat and energy generating companies should not only cover the financing of the current operating costs, but also include an investment component to finance investments in the modernization and technical re-equipment of enterprises. Technical re-equipment will stimulate more efficient use of energy resources, which, due to the cumulative effect, will contribute to a more significant reduction in the energy intensity of GDP.

Ukraine has presently adopted the Energy Strategy of Ukraine for the period up to 2030, a number of national programs, the main focus of which is on the economical use of energy resources and alternative fuels. At the same time, the analysis of the regulatory framework (EPUEI 2025). Economic policy of Ukraine in the field of energy in the context of European integration (ESU 2035). Energy strategy of Ukraine for the period up to 2035 "Security, energy efficiency, competitiveness") on the use of energy resources proved their imperfection, in particular, requires the development of a motivational mechanism to stimulate energy efficiency and the introduction of innovative measures to reduce losses of primary energy resources, etc.

The mechanism of the formation and use of energy resources unites all subjects of the fuel and energy market of Ukraine, which requires the development of a coordinated policy for their development and improvement of the economy energy efficiency as a whole. There is a need to substantiate a comprehensive system of legal, institutional and financial support for the implementation of energy efficiency and energy conservation state policy. Only a comprehensive approach to energy policy development and prioritization will reduce energy losses and increase their efficiency, which will affect the energy security of the national economy.

The essence of rational use of energy resources is to achieve maximum efficiency of their consumption at the current level of equipment and technology development and at the same time reduce the man-made impact on the environment (World Energy Council 2020). The content of the rational use of energy organization process resources is shown in Figure 2.

The irrational or inefficient use of energy resources involves direct losses of energy resources, their wasteful use and use in excess of the specific costs defined by the system of standards, and before the introduction of the system of standards – the norms of specific fuel and energy consumption.

Another fact is that today the analysis of energy security is conducted in the context of the analysis of the state economic security on a weighted sum of ten indicators that require constant review and adjustment.

Some scientists (Zelinska et al. 2020; Cherchata et al. 2020) supplement the analysis of energy security by examining groups of social, economic, environmental and technical indicators, others – by individual product determinants (gas security, oil security, oil and coal security). Each of these approaches has its drawbacks, in particular the latter – is limited to assessing the efficiency of fuel supply, eliminating a number of other criteria, namely: security of supply, efficiency, raw materials, economic stability of fuel and energy complexes. It follows that the existing methodological approaches can be used to solve individual evaluation tasks for which they were developed.
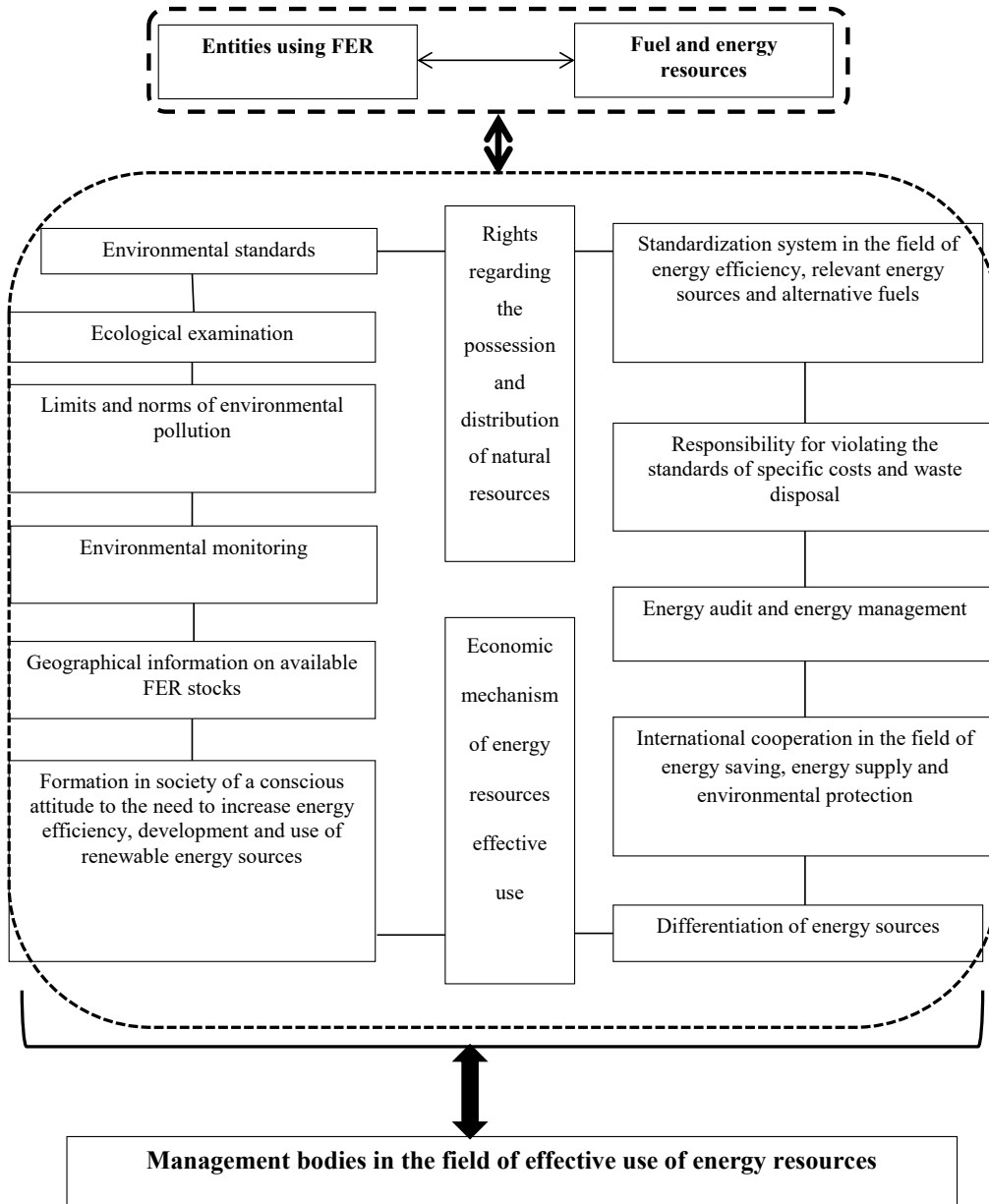
Fig. 2. Visualized scheme of an integrated approach to the organization of the process of rational use of energy resources
Source: own study

Rys. 2. Poglądowy schemat zintegrowanego podejścia do organizacji procesu racjonalnego wykorzystania zasobów energetycznych

At the same time, to substantiate structural reforms and scenarios of energy system and fuel and energy complex on the basis of energy security, we propose a comprehensive methodological approach based on the construction and formalization of deterministic economic valuation models according to certain criteria and functional features of all levels of energy security, national and regional economies, industries and enterprises.

Energy independence should be studied in the context of individual components of energy resources by fuel and energy balances, NERC reports, forms of state statistical reporting, information from the official websites of NERC, the State Statistics Service, the Ministry of Fuel and Energy, etc. We propose to consider the adequacy and efficiency of supply not only of oil, gas, petroleum products and coal, but also peat, biomass, electricity. Local fuels and energy generating capacities are the fundamental resources of economic development and the formation of energy security of the economy on local, regional, national and global levels. The system of energy independence indicators should reflect the security of own resources supply and dependence on critical imports for certain types of energy resources. Our assessment methodology allows us to compare the actual level with normative or strategic indicators according to the data of the Energy Strategy until 2030 or other national, state and regional plans and development programs or directives of the European Union.

Using the index method, we substantiate the transition from individual indicators to individual determinants and the criterion of energy independence when building a model of functional dependence. The state of energy independence is characterized by a multidimensional vector consisting of individual determinants:

$$EI = \left\{ d_e^{EI}, d_{op}^{EI}, d_c^{EI}, d_p^{EI}, d_{cc}^{EI}, d_b^{EI}, d_{ng}^{EI} \right\} \tag{1}$$

At the absolute level of energy independence, each of the determinants will have a value that approaches "1", and energy dependence will be observed when the values approach "0".

To assess the impact of these determinants on the overall energy independence, it is necessary to apply weighting factors, with a functional approach, their role in relation to individual determinants by which type of FER can perform the share of individual FER in the supply of primary energy (qi). The determination of the general indicator value of the energy independence criterion should be carried out according to the formulas of additive, multiplicative and functional convolutions (2), (3), (4), (5), (6), (7), (8).

To determine the level indicator and integrated energy security or certain criteria, you can use an additive, multiplicative convolution power performance or functional relationship. According to the additive convolution, the total scalar index is calculated by the formula:

$$E_i^k = \sum_{j=1}^{n} \left(w_j \frac{E_{ij}^{k-1}}{E_{ij}^{k-1}} \right) \atop \sum_{j=1}^{n} w_j = 1 \tag{2}$$

where

w_j – the specific weight of each criterion (indicator).

The specified model under condition of all criteria equivalence weights will get the following look:

$$ES_1 = \frac{ED + EI + ES + ER + ES}{5}$$

(3)

where:

ES_1 – energy security of the national economy,
ED – energy dependence,
EI – energy efficiency,
ES – energy security,
ER – energy reliability,
ES – economic stability.

With additive convolution, low values of indicators can be compensated by high values of other indicators. In the case of multiplicative convolution, the total scalar meter should be determined by the following dependence:

$$E_i^k = \overset{n}{\underset{i=1}{P}}(E_{ij}^{k-1} / E_{ij}^{k-1})^{w_i}$$

(4)

The peculiarity of such a convolution is the approach to the zero level of the overall indicator, if any of the partial indicators becomes zero, which corresponds to the conditions of the crisis reflection in the energy sector and energy danger. Given the equivalence of the criteria, the multiplicative model will take the following form:

$$ES = ED^{1/5} \cdot EI^{1/5} \cdot ES^{1/5} \cdot ER^{1/5} \cdot ES^{1/5}$$

(5)

In the more general case of convolution, a power function is used to build an energy security model:

$$E_i^k = \left[\frac{1}{n} \sum_{j=1}^{n} \left(\frac{E_{ij}^{k-1}}{E_{ij}^{k-1}} \right)^p \right]^{1/p}$$

(6)

$$ES_3 = \left(\frac{1}{5}(ED^P + EI^P + ES^P + ER^P + ES^P) \right)^{\frac{1}{P}}$$

where:
p – the allowable degree of compensation for small values of equivalent indicators.

The higher the "p", the higher the level of possible compensation (take $p = 0.2$).

Given the equivalence of energy security criteria, the functional models of components (Dt_i) and energy security of the national economy will be as follows:

a) for additive convolution:

$$Dt_i = (dt_i^{ED} + dt_i^{EI} + dt_i^{ES} + dt_i^{ER} + dt_i^{ES}) \div 5$$
$$ES = \sum (Dt_i \cdot w_i) \tag{7}$$

b) for multiplicative:

$$Dt_i = (dt_i^{ED})^{1/5} \cdot (dt_i^{EI})^{1/5} \cdot (dt_i^{ES})^{1/5} \cdot (dt_i^{ER})^{1/5} \cdot (dt_i^{ES})^{1/5}$$
$$ES = P(Dt_i)^{w_i} \tag{8}$$

Assessment of the individual determinants contribution to the formation of national and regional economies energy independence should be carried out in relation to the normative values of determinants calculated by normative indicators.

3. Results and discussion

The state of Ukraine's economic development generally depends on a comprehensive study of the factors influencing the energy situation in the country and the effective regulation of the industry in general. The determining factors that can affect the state of economic processes in the energy sector of Ukraine are the following:

◆ Inconsistency of FER consumption and production.
◆ Imbalance between gas purchases and gradual loss of revenues from gas transit through the territory of Ukraine due to deteriorating relations because of the war with Russia.
◆ Uncertainty of prospects for energy production within the country.
◆ High energy intensity of FER production and consumption, their low energy efficiency.
◆ Significant fluctuations in world prices for energy resources.
◆ Ukraine's slow transition to the introduction of advanced production technologies, the use of alternative energy sources, etc.

In the conditions of destabilization of Ukraine's economy functioning, an insufficient level of stocks of fuel and products of oil refining poses energy danger for the functioning of the national economy, including, and all sectors of the power system (fuel and energy complex). The national conomy of Ukraine in 2018 consumed 153,912.2 thousand tons FER, which is 2.8% less than in 2017. In the structure of resource use, 65.1% belonged to fuel, 21.4% to electricity and 13.5%

to heat. As noted, one of the main problems for the normal functioning of the energy complex of Ukraine is the mismatch between the consumption and production of energy resources, which characterizes the coverage ratio. If this ratio (the ratio of energy resources to their consumption) is more than 100%, it means that the country can fully provide energy resources for itself (population and industry). A ratio of less than 100% indicates the need to import energy resources to meet the needs of the population and the economy.

Based on the above system of indicators, we have built functional models of individual determinants of the criterion "Energy Independence" for the national economy (Table 1) and determine their value.

TABLE 1. Functional models of Ukraine's economy energy independence determinants

TABELA 1. Modele funkcjonalne wyznaczników niezależności energetycznej gospodarki Ukrainy

Determinants of energy independence		Method of determination	Years				
			2014	2015	2016	2017	2018
For electricity	=	$K_1*(1-q_2*K_2*t_2)*K_{20}$	0.057	0.059	0.048	0.061	0.068
For oil products	=	$K_{16}*(1-K_8*t_8)$	0.193	0.169	0.209	0.205	0.162
For coal	=	$K_{14}*(1-K_6*t_6)$	0.709	0.703	0.799	0.819	0.876
For peat	=	$K_{15}*(1-K_{11}*t_{11})$	2.883	3.701	4.722	3.615	2.341
For crude oil and condensate	=	$K_{13}*(1-K_7*t_7)$	0.108	0.110	0.120	0.508	0.846
By biomass	=	$K_{10}*(1+K_{21}*q_{21}*K_{22})$	1.427	1.500	1.503	1.478	1.489
For natural gas	=	$K_{12}*t_{10}*(1-K_{19}*q_{19})*(1-K_{18}*q_{18})*(1-K_9*t_9)$	0.116	0.093	0.046	0.067	0.082

Source: calculated by the authors on the basis of (The State Statistics Committee of Ukraine 2020).

where:

K_1 – the share of renewable energy in the production of electricity, unit fraction
q_2 – share of atomic energy in the supply of primary energy, unit fraction
K_2 – level of import dependence for atomic energy (by fuel), unit fraction
t_2 – share of fuel imports for the (atomic power station) APS from the dominant country (supplier), unit fraction
K_{20} – level of provision of electricity consumption by own production, unit fraction
K_{16} – level of provision of consumption of oil products by own production, unit fraction
K_8 – level of import dependence on oil products in the total supply of oil products, unit fraction
t_8 – share of import of oil products from one country in the total volume of their import, unit fraction
K_{14} – level of provision of coal consumption with own production, unit fraction
K_6 – level of import dependence on coal in the total supply of natural gas, unit fraction
t_6 – share of coal imports from the dominant country (supplier), unit fraction
K_{15} – level of security of peat consumption by own production, unit fraction
K_{11} – level of import dependence on peat and fuel from it, unit fraction
t_{11} – share of import of peat and fuel from it from the dominating country (supplier), unit fraction
K_{13} – level of provision of oil consumption with own production, unit fraction
K_7 – level of import dependence on crude oil in the total supply of natural gas, unit fraction
t_7 – share of crude oil imports from one country in the total volume of its imports, unit fraction
K_{10} – level of provision of biomass consumption, own production, unit fraction
K_{21} – share of biomass from total annual fuel consumption, unit fraction

q_{21} – share of biomass in fuel for heat production, unit fraction
K_{22} – share of substitution of natural gas consumption for heat production by biomass, unit fraction
K_{12} – the level of provision of consumption of natural gas by own production, unit fraction
t_{10} – the share of the population in the final consumption of natural gas, unit fraction
K_{19} – specific weight of deliveries of liquefied gas from one supplier, unit fraction
q_{19} – the share of apartments gasified with liquefied gas, unit fraction
K_{18} – the share of natural gas supplies from one supplier, unit fraction
q_{18} – the share of apartments gasified with natural gas, unit fraction
K_9 – the level of import dependence on natural gas in the total supply of natural gas, unit fraction
t_9 – the share of imports of natural gas from one country in the total volume of its imports, unit fraction

The analysis of Table 1 shows that electricity consumption is critical due to the low share of renewable energy and excessive dependence on imports of nuclear fuel (NPP) for nuclear power plants, however, due to the reduction of the share of nuclear power plants in the electricity supply, the determinant level increased slightly in 2017–2018. A negative value (close to zero) with a deteriorating trend was observed for natural gas due to the growth of its imports and the share in the balance of primary energy. Some improvement in the determinants of crude oil and condensate is associated with a reduction in the domestic production of petroleum products (according to energy balances in 2014–2017) and limiting imports by exports and bunkering. The results of calculating the normative values of the components of the determinants of the level of energy independence and their threshold values, which determine the critical level of the overall energy independence for the national and regional economies, are shown in Table 2.

TABLE 2. Qualitative and quantitative assessment of Ukraine's economy energy independence level
(by additive convolution)

TABELA 2. Jakościowa i ilościowa ocena poziomu niezależności energetycznej Ukrainy
(metodą splotu addytywnego)

Determinants of energy independence for additive convolution		Method of determination	2014	2015	2016	2017	2018
For electricity	=	$K_1*(1-q_2*K_2*t_2)*K_{20}*q_1$	0.011	0.011	0.009	0.012	0.013
For oil products	=	$K_{16}*(1-K_8*t_8)*q_8$	0.004	0.002	0.006	0.011	0.009
For coal	=	$K_{14}*(1-K_6*t_6)*q_6$	0.222	0.199	0.262	0.285	0.335
For peat	=	$K_{15}*(1-K_{11}*t_{11})*q_{11}$	0.003	0.004	0.005	0.004	0.002
For crude oil and condensate	=	$K_{13}*(1-K_7*t_7)*q_7$	0.011	0.010	0.009	0.021	0.048
By biomass	=	$K_{10}*(1+K_{21}*q_{21}*K_{22})*q_{10}$	0.019	0.017	0.018	0.018	0.024
For natural gas	=	$K_{12}*t_{10}*(1-K_{19}*q_{19})*$ $(1-K_{18}*q_{18})*(1-K_9*t_9)*q_9$	0.041	0.039	0.017	0.024	0.024
Energy independence of the national economy			0.311	0.281	0.326	0.374	0.455

Source: calculated by the authors on the basis of (The State Statistics Committee of Ukraine 2020).

where:

q_1 – share of electricity production without consumption of fossil fuels in the total supply of primary energy, unit fraction

K_{16} – level of provision of consumption of oil products by own production, unit fraction
K_8 – level of import dependence on petroleum products in the total supply of petroleum products, unit fraction
t_8 – the share of imports of petroleum products from one country in total imports, unit fraction
q_8 – the share of petroleum products in the supply of primary energy, unit fraction
K_{14} – level of provision of own consumption of coal, unit fraction
K_6 – level of import dependence on coal in the total supply of natural gas, unit fraction
t_6 – share of coal imports from the dominant country (supplier), unit fraction
q_6 – the share of coal in the supply of primary energy, unit fraction
K_{15} – level of self-extracted peat consumption, unit fraction
K_{11} – level of import dependence on peat and fuel from it, unit fraction
t_{11} – share of imports of peat and fuel from it from the dominant country (supplier unit fraction
q_{11} – the share of peat in the supply of primary energy, unit fraction
K_{13} – level of provision of oil consumption with own production, unit fraction
K_7 – level of import dependence on crude oil in the total supply of natural gas, unit fraction
t_7 – share of crude oil imports from one country in total imports, unit fraction
q_7 – share of crude oil in primary energy supply, unit fraction
K_{10} – level of provision of biomass consumption, own production, unit fraction
K_{21} – share of biomass in total annual fuel consumption, unit fraction
q_{21} – share of biomass in fuel for heat production, unit fraction
K_{22} – share of substitution of natural gas consumption for heat production by biomass, unit fraction
q_{10} – share of biofuels and waste in primary energy supply, unit fraction
K_{12} – level of provision of natural gas consumption with own production, unit fraction
t_{10} – share of population in final consumption of natural gas, unit fraction
K_{19} – specific weight of liquefied gas supplies from one supplier, unit fraction
q_{19} – share of apartments gasified with liquefied gas, unit fraction
K_{18} – share of natural gas supplies from one supplier, unit fraction
q_{18} – share of apartments gasified with natural gas, unit fraction
K_9 – level of import dependence on natural gas in the total supply of natural gas, unit fraction
t_9 – share of natural gas imports from one country in total imports, unit fraction
q_9 – the share of natural gas in the supply of primary energy, unit fraction

The use of additive convolution allows to assess the absolute level of energy independence and the contribution of each of the determinants in its formation. The use of the share in the supply of primary energy ensures that the impact of structural changes in the fuel and energy balances is taken into account.

From 2014–2018, the energy independence of Ukraine's economy increased by 0.144 shares per unit due to energy independence determinants for coal (+0.113) and crude oil with condensate (+0.037), for electricity (+0.002), for biomass (+0.005), for petroleum products (+0.005). The positive growth dynamics of all determinants, except for natural gas and peat, can also be traced according to Table 1. The assessment of the qualitative level of energy independence requires a comparison of the actual values of the determinants and the general indicator with the normative ones, which will allow for assessing the achievement of the normative or planned level. The regulatory indicators are given in Table 3.

From 2014–2018, there was an insufficient level of energy independence of the national economy (<0.340) due to the low level of determinants for petroleum products, peat, crude oil and condensate, biomass relative to the normative indicators of 2020. The determinant for natural gas exceeds or approaches the normative level during the entire study period except 2016. Energy

TABLE 3. Normative assessment of the energy level independence of the economy of Ukraine
(by additive convolution)

TABELA 3. Normatywna ocena niezależności energetycznej gospodarki Ukrainy
(metodą splotu addytywnego)

Determinants of energy independence	Ukraine			
	2020	2025	2030	2035
For electricity	0.012	0.015	0.016	0.022
For oil products	0.012	0.018	0.020	0.012
For coal	0.236	0.227	0.222	0.213
For peat	0.010	0.010	0.010	0.010
For crude oil and condensate	0.063	0.056	0.057	0.057
By biomass	0.098	0.100	0.091	0.090
For natural gas	0.021	0.022	0.025	0.026
Energy independence	0.453	0.449	0.442	0.429
Danger	0.113	0.112	0.111	0.107
Insufficient	0.226	0.224	0.221	0.215
Sufficient	0.340	0.337	0.332	0.322
Safe	0.407	0.404	0.398	0.387
Absolute	0.453	0.449	0.442	0.429

Source: calculated by the authors on the basis of (The State Statistics Committee of Ukraine 2020).

independence in 2017 reached the absolute level of 2020–2035, but its provision requires the implementation of measures to expand the use of biomass, peat and other renewable energy sources for electricity, heat and solid fuels, increase its own production of natural gas and oil with condensate, resume the production of petroleum products. The need to create its own production of nuclear fuel (Fuel) for nuclear power plants and the search for alternative suppliers to increase the determinant of electricity to the normative level in 2035 deserves considerable attention. Exceeding the normative level for 2020–2025 by the determinant of energy independence of Ukraine's economy for natural gas characterizes a sufficient level of energy independence and the possibility of replacing this resource by using alternative fuels and energy, diversifying suppliers and increasing its own natural gas production.

The main disadvantage of determining the total energy independence index by additive convolution is the compensation of small values of individual determinants (which can be critical for the economy). This situation can be prevented by using a multiplicative convolution (Table 4).

If the determinants of energy independence, determined by multiplicative convolution, reach the value "1", this indicates local energy independence for this type of FER, and if approaching zero – the local energy independence for a particular type of resource. To substantiate this approach, we determine the normative level of energy independence and its determinants by mul-

TABLE 4. Qualitative and quantitative assessment of Ukraine's economy energyindependence level
(by multiplicative convolution)

TABELA 4. Jakościowa i ilościowa ocena poziomu niezależności energetycznej gospodarki Ukrainy
(metodą splotu multiplikatywnego)

Determinants of energy independence for multiplicative convolution		Method of determination	2014	2015	2016	2017	2018
For electricity	=	$(K_1*(1-q_2*K_2*t_2)*K_{20})^{\wedge}q_1$	1.000	1.000	1.000	1.000	1.000
For oil products	=	$(K_{16}*(1-K_8*t_8))^{\wedge}q_8$	0.964	0.977	0.959	0.918	0.903
For coal	=	$(K_{14}*(1-K_6*t_6))^{\wedge}q_6$	0.898	0.905	0.929	0.933	0.951
For peat	=	$(K_{15}*(1-K_{11}*t_{11}))^{\wedge}q_{11}$	1.001	1.001	1.002	1.001	1.001
For crude oil and condensate	=	$(K_{13}*(1-K_7*t_7))^{\wedge}q_7$	0.801	0.823	0.859	0.973	0.991
By biomass	=	$(K_{10}*(1+K_{21}*q_{21}*K_{22}))^{\wedge}q_{10}$	1.005	1.004	1.005	1.005	1.006
For natural gas	=	$(K_{12}*t_{10}*(1-K_{19}*q_{19})*$ $(1-K_{18}*q_{18})*(1-K_9*t_9))^{\wedge}q_9$	0.463	0.368	0.319	0.387	0.486
Energy independence of the national economy			0.323	0.269	0.246	0.325	0.417

Source: calculated by the authors on the basis of (The State Statistics Committee of Ukraine 2020).

tiplicative convolution relative to the indicators of the baseline scenario of the energy strategy, national and regional programs, energy balances of Ukraine (Table 5).

The level of energy independence of Ukraine's economy in 2018 is absolutely relative to the normative indicators of all forecast time periods. According to the normative assessment, the level of energy independence in 2014, 2017, 2018 relative to 2020 is absolute, relative to 2025 – safe, relative to 2030 and 2035 – sufficient, in 2015 it is an order of magnitude lower than the previous period, and in 2016 – by two orders of magnitude relative to the level of 2014. The results of comparing the levels of energy independence by additive and multiplicative convolutions are presented in Table 6.

According to the threshold values of the energy independence level (0 – critical energy dependence; 0.25 – energy dependence; 0.5 – insufficient level; 0.75 – sufficient level; 0.9 – safe; 1.0 – absolute) in all periods except 2018 and in relation to all regulatory indicators, a critical energy dependence level of the national economy can be traced by additive convolution, and in 2018 – the situation was characterized by significant energy dependence. At the same time, according to the proposed methodology, the state of energy independence is characterized as insufficient, not dangerous. The results of the multiplicative convolution usage in the traditional approach are identical to those obtained using the proposed theoretical and methodological approach (the total energy independence becomes zero) and signal a critical level or danger of energy dependence.

Table 5. Normative assessment of Ukraine's economy energy independence level
(by multiplicative convolution)

Tabela 5. Normatywna ocena poziomu niezależności energetycznej gospodarki Ukrainy
(metodą splotu muliplikatywnego)

Determinants of energy independence	Years			
	2020	2025	2030	2035
For electricity	0.618	0.632	0.604	0.637
For oil products	0.997	0.989	0.986	0.992
For coal	0.993	0.993	0.994	0.995
For peat	1.000	1.000	1.000	1.000
For crude oil and condensate	0.988	0.988	0.988	0.990
By biomass	1.000	1.000	1.000	1.000
For natural gas	0.486	0.575	0.625	0.663
Energy independence	0.294	0.353	0.366	0.413
Danger	0.073	0.088	0.091	0.103
Insufficient	0.147	0.177	0.183	0.206
Sufficient	0.220	0.265	0.274	0.310
Safe	0.264	0.318	0.329	0.372
Absolute	0.294	0.353	0.366	0.413

Source: calculated by the authors on the basis of (The State Statistics Committee of Ukraine 2020).

Table 6. The results of assessing Ukraine's economy energy independence level

Tabela 6. Wyniki oceny poziomu niezależności energetycznej gospodarki Ukrainy

Years	convolution	Predictive value			
		2020	2025	2030	2035
2014	adaptive	insufficient	insufficient	insufficient	insufficient
	multiplicative	absolute	safe	sufficient	sufficient
2015	adaptive	insufficient	insufficient	insufficient	insufficient
	multiplicative	safe	sufficient	insufficient	insufficient
2016	adaptive	insufficient	insufficient	insufficient	sufficient
	multiplicative	sufficient	insufficient	insufficient	insufficient
2017	adaptive	sufficient	sufficient	sufficient	sufficient
	multiplicative	absolute	safe	sufficient	sufficient
2018	adaptive	absolute	absolute	absolute	absolute
	multiplicative	absolute	absolute	absolute	absolute

Source: own study.

Conclusions

Thus, this study found that there are many factors in Ukraine that negatively affect the development of its energy sector, due to the lack of competitiveness of technology, the instability of the political and economic situation, which affect the development of external relations.

A comprehensive approach to ensuring the rational use of energy resources has been proposed and developed, which will contribute to the implementation of the effective energy saving policy of the state, ensuring the competitive advantages of domestic enterprises, increasing their competitiveness, and improving the economic and energy security of Ukraine. Taking this approach into account when developing an energy saving program will allow for concentrating available resources and optimizing the efficiency of their use by assessing individual components of the energy independence of Ukraine's economy. The determined economic models of providing the national economy with energy resources are built and formalized and on their basis the system of functional models of separate determinants, criteria, components and general measures of energy security of national and regional economies is determined. They take the interactions and functional interactions between individual hierarchical levels of energy security into account. When substantiating and evaluating energy policy measures, stress testing of critical threats and quantitative and qualitative assessment of energy security of Ukraine's economy is proposed.

The prospect of further research in this area is to develop methodological tools for a comprehensive assessment of the rational use of energy resources at different levels of management of Ukraine's economy.

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Modelowanie i prognozowanie zużycia paliw i energii w kontekście niezależności energetycznej Ukrainy

Streszczenie

W artykule dokonano analizy struktury zasobów energetycznych, w której wyniku ujawniono przyczyny ich nieracjonalnego wykorzystania w ukraińskiej gospodarce. Ustalono, że w latach 2014–2018 nastąpił spadek zapotrzebowania na tradycyjne rodzaje paliw i surowców energetycznych, z wyjątkiem węgla. Elementy składowe procesu zaopatrzenia i zużycia paliw i surowców energetycznych zostały określone w sposób szczegółowy oraz wypracowano zintegrowane podejście do ich racjonalnego wykorzystania, które ograniczy utratę zasobów energetycznych i zwiększy ich efektywność. Autorskie podejście wykorzystywane jest w postaci poglądowych schematów organizacji procesu racjonalnego wykorzystania surowców energetycznych, co przyczyni się do realizacji skutecznej polityki oszczędzania energii w kraju, zapewniając przewagę konkurencyjną rodzimym przedsiębiorstwom poprzez zwiększenie ich atrakcyjności, poprawę bezpieczeństwa gospodarczego i energetycznego Ukrainy. Uzasadniono i udowodniono celowość konstruowania deterministycznych modeli ekonomicznych ukraińskiej gospodarki według różnych (adaptacyjnych i multiplikatywnych) splotów funkcji, na podstawie których przedstawiono prognozę i ocenę niezależności energetycznej ukraińskiej gospodarki do 2035 roku, z uwzględnieniem paliw i zasobów energetycznych. Na podstawie obliczeń ustalono, że stan niezależności energetycznej Ukrainy jest niewystarczający.

Słowa kluczowe: niezależność energetyczna, Ukraina, zasoby paliw i energii, model, podejście, prognozowanie