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SUSTAINABLE DEVELOPMENT OF THE ECONOMY IN THE CONDITIONS OF THE ENERGY CRISIS

Purpose. To establish the factors of the impact of the energy crisis on the formation of a sustainable economy. To propose a method for forecasting the balance of energy production and consumption. To establish the level of correlation between sustainable development indicators and energy indicators.

Methodology. Cognition methods were used to perform the work: analysis and synthesis to choose the topic and purpose of the study; content analysis for literature review; critical analysis to identify unsolved aspects of the problem and national characteristics of the crisis; the ascent from the abstract to the concrete to prove the relationship between the energy crisis and achievement of the sustainable development goals (SDG); system analysis to substantiate the need for energy balance and import substitution of energy resources; induction and deduction for the selection of SDGs, which are affected by the energy crisis and energy balance forecasting models, establishing the level of correlation with SDG indicators; idealization and formalization to identify factors inhibiting the formation of a sustainable economy.

Findings. It is established that in addition to the global factors of the energy crisis, national economies have their own factors influencing the pace of achieving the SDG. The main reasons for the gap between energy production and consumption and trends in import substitution in the energy sector are indicated. The presence of direct and reverse effects of energy development and sustainable development is proved. It is established that the solution to the problem of sustainable economic development is to systematically ensure the dynamic balance of production and consumption of energy, and import substitution of energy resources.

Originality. The reasons for reducing the level of relevance of forecasting and energy plan required to achieve the SDG are identified. There is a significant level of correlation between the Mtoe indicator and groups of SDG indicators and the fact that indicator of relative fluctuations as for average Mtoe is an integral indicator of the SDG achievement.

Practical value. The MCDA method and a quantitative approach to its implementation are proposed to forecast energy consumption and to model sustainable development scenarios.

Keywords: *energy crisis, sustainable development, technological renewal, import substitution of energy resources*

Introduction. The development of the economy in modern conditions, even with the goal of achieving sustainable development, leads to an increase in energy consumption.

The rapid introduction of electronic devices, appliances that consume electricity, the growing needs of the population in the face of increasing its number leads to a steady increase in energy consumption for household needs.

Technological renewal of industry, transport, agriculture and other industries also leads to a sharp increase in energy consumption.

Attempts to reduce environmental pollution associated with energy production, in particular carbon pressure on the biosphere, result in significant capital expenditures in energy.

The growing gap between energy production and energy consumption leads to the formation of crisis conditions in the energy sector. Moreover, the energy sectors, which account for the largest share in total energy production, suffer the most.

This, in turn, limits the pace of implementation of a sustainable economy and leads to a failure to meet the deadlines set in government programs and intergovernmental documents to achieve the Sustainable Development Goals (SDG).

In these circumstances attempts to prevent the energy crisis and at the same time ensure the acceleration of sustainable economic development by increasing the pace of technological renewal in industry and household sphere encounter certain limitations: lack of investment in these areas; inconsistency in the goals of research groups and society; non-compliance of the pace of renewal with the needs of sustainable development, etc.

This poses a challenge to human development in general, and to the development of national economies in particular.

Literature review. The presence of the impact of the crisis in the energy sector and the achievements of the SDG are indicated in many works, but in a significant number of works this is done only in general. In particular, this is indicated in the analysis of the pace of energy development of the Republic of Moldova [1]. But the study did not reveal the reverse nature of this effect and the causes of the crisis, and did not establish a correlation between SDG indicators and energy indicators. In the article [2], its nature to determine the presence of this correlation is not analyzed. The problems of energy losses were also identified for the formation of reliable economic results of energy production, but the impact of energy losses on sustainable development was not demonstrated. Analyzing the genesis of the Concept of Sustainable Development [3], it was noticed that some SDGs are interconnected, the need to adapt to the crisis was established. However, the impact of the energy crisis on the formation of a sustainable economy has not been sufficiently studied. For our work it was useful to conclude that development should be seen as a comprehensive structural transformation.

An attempt to mathematize the relationship between the satisfaction of energy production and energy consumption as a substantiation for the conditions for achieving SDG [4] with the rationality of the general approach allowed us to formulate the objectives of our study more accurately. However, it was not possible to use the presented model due to the low relevance because of the use of the additive method. A systematic review [5] focuses on the need to ensure energy adequacy as a means of avoiding a crisis for a sustainable economy. But the nature of this impact and the presence of its peculiarities for national economies have not been identified. In [6] the analysis of GDP growth is given, the increase in the use of energy resources for this purpose is emphasized, the formation of preconditions of the crisis, which violates the terms of achievement of SDG, is indicated. But the nature of the interaction of these factors was overlooked.

The cited literature indicates that the scientific community understands the dangers of the energy crisis to achieve SDG, but only some scientists [4] offer mathematical approaches to predict the situation. The presence of this problem encourages scientists to find ways to overcome it. In particular, in [7] the strategic implementation of energy policy is proposed in view of the achievement of SDG and avoidance of the consumption crisis, provided that the needs of the population are met. An analysis of the policy package for energy supply at the micro and meso levels, which is called complex in [7], suggests a way to reduce energy consumption to avoid a crisis. Unfortunately, the paper does not propose relevant forecasting tools for the implementation of this policy. The study [8] proposed an approach to quantifying SDGs and their energy needs to forecast energy demand for energy planning as part of SDG implementation. The proposed approach, unfortunately, does not provide sufficient relevance of forecasts, but the direction of work is promising and was used in our study. The path of crisis-free energy use upon the condition of providing SDG is given in [9]. The main goal is to achieve the environmental goals of the SDG, environmental sufficiency and efficiency for developed countries, and energy poverty policy for pre-development countries. But this path does not allow a comprehensive solution to the SDG and leads to international segregation.

The article [10] emphasizes the need to increase the share of clean energy and quantifies the relationship between energy quality and quality of life (QoL). But in general, this does not solve the problem of the gap between energy production and energy consumption. In [11], the global final demand for energy is projected to decrease by 2050 by 245 EJ, which is 40 % of the current level on the conditions of integrated SDG supply. That is, they indicate that the problem of the gap between energy production and energy consumption will be solved naturally. Based on the forecast [11, 12] the practical minimum threshold of final energy consumption required to provide SDG is estimated. The way to implement the energy balance to move from non-renewable energy sources to renewable ones for strategic management using a macroeconomic module within the system dynamics model (MEDEAS) was developed by the authors [13]. But neither in [11], nor in [12], nor in [13] the technological support of the balance of SDG and energy production has been proved. Moreover, the inequality of opportunities given by [14] to provide SDG with the difference between cross-border and domestic energy impact for different economies indicates a strong constraint for the implementation of the energy balance. This served as a stimulus for our study to find a mechanism to neutralize this factor.

However, increasing the share of renewable energy sources distributed territorially for the implementation of long-term government support also contributes to the formation of energy balance without external energy supply to achieve SDG, environmental, social (including job creation) goals, etc. [15]. This is confirmed by proving in [16, 17] the link between the use of renewable energy sources to avoid the energy crisis and subsequent economic growth of developing countries, but this path is not a panacea, because, as it is proved in [16], the country must exceed a certain threshold of renewable energy consumption to avoid the crisis. In [17] it is stated that energy saving policy does not have a negative impact on the economic development of developing countries and thus – a negative impact on the achievement of the SDG. However, the mentioned works do not indicate that the policy of introduction of renewable sources is effective only when it is based on reliable forecasting models.

In this context, it is interesting to mention the study [18], which proposed a comprehensive approach to energy balance planning, implementation of modeling a holistic system of technological, political, economic and other factors. The model uses the methodology of integrated estimation, in particular the multiplicative form of the integrated index. This direction is used in our study.

Peculiarities of energy efficiency policy in the context of economic security for the formation of Ukraine's sustainable development economy are analyzed in [18]. The authors of the article consider the crisis not as a decline, but as an incentive for the formation of a sustainable economy of the future [19].

Also, the analysis of the direction proposed in [20] – solving the energy efficiency of Ukraine with a comprehensive solution to the energy trilemma – was useful for our study.

The purpose of the article is to study the impact of the energy crisis on the formation of a sustainable economy, to propose a method for forecasting the balance of energy production and consumption, to establish the level of correlation between sustainable development indicators and energy indicators.

Methods. Analysis of the literature indicated the need to use a systematic method to solve problems.

The method of content analysis indicated that achieving the appropriate level of energy efficiency is an integral part of the so-called "energy trilemma" [20] to ensure adequate environmental sustainability, promote a free energy market, and stimulate investment in the energy sector. That is, this is the path of economic development that determines the formation of sustainable development.

As the analysis showed, in addition to the global factors of the energy crisis, each of the national economies has its own factors of the crisis's impact on achieving sustainable economic development. This determines the existence of national characteristics of the crisis and, accordingly, the specifics of achieving the goals of sustainable development for each country.

Using the method of comparative analysis, it is proved that the energy crisis in Ukraine is characterized by the fact that since 2015 the volume of energy consumption has been ~56 % of the energy supply. Using the method of comparative analysis, it is proved that such a gap in the volume of supply and consumption of energy was the result of:

- the beginning of the war unleashed by the Russian Federation, which led, in particular, to the exclusion from the general statistics of energy consumption of the occupied territories of Ukraine – the Crimea and parts of Donetsk and Luhansk regions;
- economic crisis in the country;
- radical restructuring of the primary electricity market.

Prior to the start of hostilities in 2014, the balance of imported and nonborrowed electricity tended to reduce energy imports.

Despite the positive trends of economic indicators for the next period of 2016–2017, in particular, GDP growth compared to the beginning of the war, increasing production, positive trends in export performance, natural gas imports for the same period increased by ~64.7 % of oil and oil products ~50.4 %, coal by ~66.2 %. This is evidence that the reduction in energy dependency indicators has reached critical levels and the policy on the predominant use of domestic resources needed to be revised during this period.

This necessitated strategic planning, and the method of mathematical formalization was used for its effective implementation.

Results. Two main components need to be identified: the industrial and household sectors in analyzing energy consumption trends.

The reasons for inefficient energy consumption in the household sector, according to the results of the analysis, are mainly: technological backwardness of infrastructure; technical condition of residential buildings; low energy consumption culture. These reasons form a set of shortcomings that cannot be overcome by acting in only one direction. That is, even significant one-time investments in technological renovation of infrastructure and residential buildings, without changing the public's understanding of the need for economical use of energy resources will not lead to significant effects. The same gap exists between the needs of technical and technological renewal in industry to ensure the appropriate level of economic competitiveness and the lack of understanding of business owners, management and staff the need for additional financial and resource costs to achieve environmental, general economic and social SDG.

This is confirmed by the analysis which established the relationship between the energy crisis and the slowdown in the achievement of the SDG in Ukraine.

This relationship is characterized as multifactorial. The influence of some factors is synergistic, some are of a compromising character. However, the presence of both direct and reverse effects of the pace of development and technological renewal of energy and the pace of implementation of sustainable development ideas has been proven.

The solution to the problem of sustainable economic development in the energy crisis, in our opinion, is to implement a system approach. This approach consists both in the use of programs aimed at technological renewal of energy production and energy consumption, and in the development of a coherent policy for the implementation of sustainable development in times of crisis. This policy should have the following characteristics: it should be realistic, highly adaptable, and should create a situation instead of dealing with its consequences.

As it was mentioned above, the growing gap between energy production and energy consumption creates the preconditions for a crisis. This, in turn, limits the pace of implementation of a sustainable economy, leading to a violation of the SDG deadlines set in government programs and intergovernmental documents. The pace of technological renewal of energy can help reduce this gap by increasing the volume of energy production but not the volume of its consumption.

This leads to a lack of strategic planning to match the pace of SDG implementation and energy volumes.

Feedback is due to several factors. First, the forecasting of public policy in all areas must be consistent. And the lack of relevant strategic planning to match the pace of implementation of SDG and energy production causes non-compliance with the deadlines for achieving SDG. In turn, the failure of those SDGs which should form a rational energy consumption increases the growth of the gap between energy production and energy consumption in a multiplier way, i.e. creates the preconditions for a crisis.

In particular, in order to avoid energy crises and to continuously implement the SDG, efforts should be made to balance energy production and adjust its pace depending on forecasting the results of the stages of achieving the relevant indicators of each of the sustainable development goals. Import substitution of energy resources is also important, as it contributes to the country's energy security, economic growth, employment and increasing the number of tools to influence economic sustainability.

The analysis showed that not all sustainable development goals correlate with energy indicators. In particular, goals 10, 14, 15 and 16 do not have close and direct links with energy demand. At the same time, since the achievement of sustainable development cannot be realized only by a single sample of goals from a single set of SDGs, and these goals 10, 14, 15 and 16 may indirectly affect the achievement of other goals, excluding them from the presented study on the analysis of the impact of the energy crisis on the SDG implementation, we should not forget about the need to implement a policy of coordination to achieve the full range of goals.

With different models of energy consumption forecasting, in particular, LEAP ("planning long-term energy alternatives"), OSeMOSYS ("open source energy modeling system"), NEMS, MARKAL and others, at present there are no models that can model energy consumption related to individual SDGs. Moreover, there are no models that can predict additional energy consumption due to the indirect impact of some SDGs on others.

This leads to a lack of strategic planning to reconcile the pace of implementation of the SDG and the amount of energy required for this, which, in turn, creates an uneven nature of the achievement of the SDG. It is difficult to predict that the process of achieving SDG from a mathematical point of view is not described as a continuous function, but rather a "piecewise continuous" function, so that this process is more of an iterative approach to the goal.

In turn, the inability to develop a relevant energy plan needed to achieve the SDG by the planned time creates a barrier to the introduction of a sustainable economy in the world as a whole and in individual countries in particular.

Planning for the introduction of technological renewal of energy production and consumption as tools to avoid the energy crisis and achieve SDG is also characterized by a low level of relevance.

In particular, the level of renewable energy development, which would avoid the risks of the energy crisis affecting the SDGs if domestic production is used to meet domestic energy needs, is insufficient both worldwide (Fig. 1) and for national economies. For example, for Ukraine, the indicator of energy implementation while using renewable sources does not exceed 3.1 %. This actually leads to a negative synergy effect of the energy crisis for developing economies, including Ukraine.

For Ukraine, as a country in transition, the most effective method of decision-making to achieve SDG while ensuring a balance between energy production and energy consumption in future periods of infrastructure recovery after the active phase of hostilities, can be a scenario method of step-by-step selection of decision trees with the use of multicriteria analysis of the so-called Multi-Criteria Decision Analysis (MCDA). This is due to the fact that the MCDA method provides a comparison of several alternative solutions; it also provides an opportunity to make an informed choice from a set of proposals for the most and least suitable options as well as implements a multifactor comparison of options using multi-criteria analysis, which provides a solution that satisfies experts with different views of the target criterion of optimality.

The MCDA method is used to take into account economic, environmental and social parameters of development, which is acceptable for choosing alternatives for sustainable development of the country, provided that the mentioned energy trilemma is resolved and long-term consequences of the choice are relevantly considered.

There are two approaches to implementing the MCDA: qualitative and quantitative. The quantitative approach

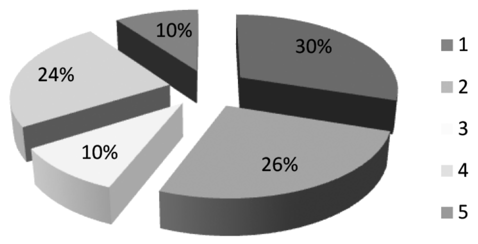

Fig. 1. The share of energy in covering domestic energy needs through domestic production:

1 – oil; 2 – coal; 3 – electricity; 4 – natural gas; 5 – renewable energy should be based on the analysis of all SDG indicators, including their multicollinear impact. Reliable methods for taking into account the multicollinear influence of indicators have not yet been proposed. The quantitative approach also requires a holistic complete set of all the data needed for analysis. Forming such a set is quite a challenge, even for large research teams. These facts point to the difficulty of using a quantitative approach and limit the relevance of its results.

The method for applying a qualitative approach is based on the following algorithm: the formation of a limited number of groups of indicators and expert decision-making based on mathematical analysis of integrated numerical indicators for selected groups of indicators.

Therefore, we propose to apply a qualitative approach to the implementation of the MCDA and to the modeling of sustainable development scenarios.

The formation of a limited number of groups of indicators should be carried out in such a way as to exclude their multicollinear influence. A step towards this is also to limit the number of SDGs, the achievement scenarios of which are the purpose of the analysis.

As a practical example of data formation for the MCDA method, a comparison of Mtoe, i. e. "Coverage of domestic energy needs at the expense of domestic production" (Table) and groups of indicators [18].

To analyze the relationship between groups of indicators of sustainable development (Fig. 2) and the balance values of energy consumption and energy production (Table) data from the National Statistics Service were used and a systematic approach to indicative representation was provided in the scientific work [18].

A systematic approach to the indicative presentation of the problem is used because it allows combining indicators into specific groups. This allows one, firstly, to exclude the multicollinear interaction of indicators, and secondly, to use not a significant number of indicators, but only a limited number of their representative groups for analysis. The sustainable development goals to be analyzed in this case are as follows: Goal 7 "Affordable and Clean Energy", first of all, sub-goals: 7.1 "Expand infrastructure and modernize networks to ensure reliable and sustainable energy supply through innovative technologies", 7.4 "Improve energy efficiency"; Goal 11 "Sustainable development of cities and communities", first of all, sub-goal: 11.5 "Reduce the negative impact of pollutants, including the urban environment, in particular through the use of innovative technologies", also goals 12, 13 and 17.

According to the analysis of the data on Mtoe, (Table), the relative significant changes in fluctuations relative to the annual average are typical for countries whose economies are far from stable. That is, it was established that this factor, for the

Table

Coverage of domestic energy needs at the expense of domestic production (million tons of oil equivalent)

Country	Years															
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Ukraine	252	252	220	195	166	164	150	144	136	135	134	134	136	141	142	141
Romania	62	51	46	46	43	47	48	45	41	36	36	37	38	40	39	39
Czech Republic	50	45	45	43	41	42	43	43	42	39	41	42	43	45	46	45
Norway	21	22	22	24	23	24	23	24	25	26	26	27	25	27	27	27

Country	Years															δ, %
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	
Ukraine	137	139	135	114	132	126	122	116	106	93	92	89	93	89	96	20.6
Romania	40	40	40	35	35	36	35	32	32	32	32	32	32	32	32	13.8
Czech Republic	46	46	45	43	45	43	43	43	42	42	41	43	43	43	39	3.86
Norway	27	27	28	32	33	28	31	33	29	30	29	30	29	28	27	9.3

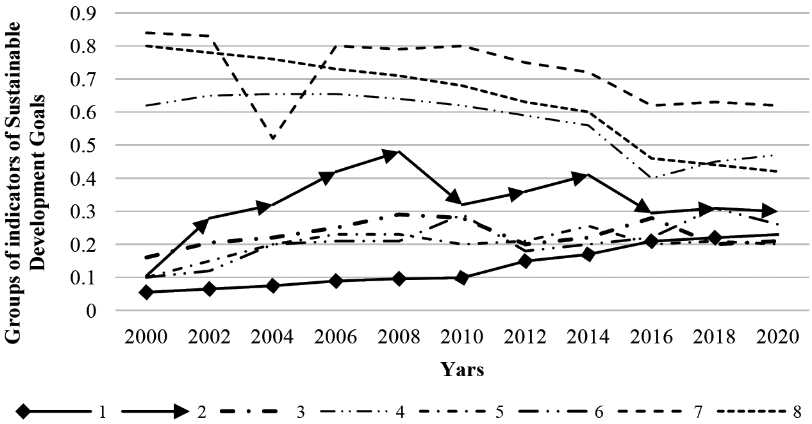

Fig. 2. Dynamics of groups of indicators:

1 – resource sufficiency; 2 – economic acceptability; 3 – resource and technological security; 4 – socio-political expediency; 5 – affordability; 6 – environmental acceptability; 7 – institutional and organizational support; 8 – compliance with the objectives numerical representation of which the indicator δ – the ratio of the average linear deviation of Mtoe from the average value for the period was used, can be used as an integrated indicator of the level of sustainable development. For example, the indicator for Norway is more than twice as small as for Ukraine and the indicator for the Czech Republic is 5.4 times less than that for Ukraine (Table).

Indicator δ which is used in Table was calculated by the formula

$$\delta = \left\{ \left[\sum_{1}^{n} (q_i - \underline{q}) \right] \Big/ n \right\} \Bigg/ \left\{ \frac{\left(\sum_{1}^{n} q_i \right)}{n} \right\},$$

where q_i is the annual value of the Mtoe indicator for each country; $\underline{q}$ is the average value of Mtoe for a period of n years. That is, the value of the average linear indicator Mtoe relative to the average was calculated for 31 years.

European countries that are not among the most developed economies were selected to illustrate the change in Mtoe. Detailed analysis of Table provides an opportunity to assess the long-term trends in Mtoe and see the impact of the crisis on this indicator.

The analysis established a significant level of correlation between the Mtoe indicator for Ukraine and the groups of indicators of sustainable development. Thus, the correlation coefficient for resource sufficiency is 0.961; 4 – socio-political expediency – 0.962; environmental acceptability – 0.452; institutional and organizational support – 0.41; compliance with the goals – 0.954. This indicates a significant level of correlation. At the same time, by groups of indicators the results are as follows: economic acceptability, economic affordability, and resource and technological security, the correlation coefficient is insufficient and is 0.003, 0.295 and 0.04, respectively, which characterizes the technological insecurity in this direction and the insufficient level of implementation of market factors in the energy sector.

As the results of the analysis showed, the main factors that hinder the process of forming an energy-efficient economy of Ukraine and, thus, the formation of prerequisites for the formation of a sustainable economy are:

- the growing gap between the volumes of energy production and energy consumption, which forms the preconditions for the crisis, which multiplicatively causes the lack of resources for technological renewal of energy, increasing its level of energy efficiency;
- irrelevance of forecasting and planning the rates of energy production and energy consumption, which leads to violation of the planned deadlines of the SDG group.

Conclusions. It is stated that economic sustainability during the energy crisis is an integral part of the energy trilemma.

It is established that in addition to the global factors of the energy crisis, national economies have their own factors influencing the pace of achieving sustainable economic development. The main reasons for the gap in production and consumption of energy and trends in import substitution in the energy sector of Ukraine are indicated.

The existence of direct and reverse effects of the pace of development and technological renewal of energy and the pace of sustainable development and the multifactorial nature of their relationship have been proven. It is established that the influence of some factors is synergistic, some have a compromising character.

It is stated that the solution to the problem of sustainable economic development in the energy crisis is to implement a systematic approach, first of all to ensure a dynamic balance of energy production and consumption as well as import substitution of energy resources, as it contributes to energy security, economic growth, employment and the number of tools to influence the sustainability of the economy.

It is established that not all SDGs correlate with energy indicators and the range of goals that will help to avoid the energy crisis is indicated.

The models of energy consumption forecasting are analyzed and the expediency of the MCDA method and the quantitative approach to its implementation are substantiated. The MCDA method for modeling sustainable development scenarios is proposed.

A comparison of Mtoe and groups of sustainable development indicators is considered in order to form data sets for the MCDA method. A systematic approach to the indicative presentation of the problem allows combining indicators into groups, which eliminates the multicollinear interaction of indicators and limits the number of their representative groups.

A significant level of correlation has been established between the Mtoe indicator for Ukraine and the groups of sustainable development indicators. Relatively significant changes in fluctuations relative to the annual average, typical of countries whose economies are far from stable have been detected. It is established that the indicator of relative fluctuations as for the average annual Mtoe indicator can be used as an integrated indicator of the level of sustainable development.

The main factors that hinder the process of forming an energy-efficient economy of Ukraine and, thus, the formation of preconditions for the formation of a sustainable economy have been identified.

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Стійкий розвиток економіки в умовах енергетичної кризи

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Мета. Встановити фактори впливу енергетичної кризи на формування сталої економіки. Запропонувати метод прогнозування балансу виробництва та споживання енергії. Встановити рівень кореляції індикаторів сталого розвитку та енергетичних показників.

Методика. Методи пізнання використані для виконання роботи: аналізу й синтезу для вибору теми й мети дослідження; контент-аналізу для огляду літератури; критичного аналізу для виявлення невирішених аспектів проблеми та національних особливостей кризи; сходження від абстрактного до конкретного для доведення взаємозв'язку енергетичної кризи та досягнення цілей стійкого розвитку (SDG); системного аналізу для обґрунтування необхідності енергобалансу та імпортозаміщення енергоресурсів; індукції й дедукції для вибору SDG, на які впливає енергетична криза та моделі прогнозування енергобалансу, встановленню рівня кореляції з індикаторами SDG; ідеалізації та формалізації для виявлення чинників, стримуючих формування сталої економіки.

Результати. Встановлено, що окрім загальносвітових чинників енергетичної кризи для національних економік є власні чинники впливу на темпи досягнення SDG. Указані основні причини розриву між обсягами виробництва й споживання енергії та тренди імпортозаміщення в енергетичному секторі. Доведена наявність прямого та зворотного впливу темпів розвитку енергетики й сталим розвитком. Встановлено, що вирішення проблеми сталого розвитку економіки полягає в системному забезпеченні динамічного балансу виробництва й споживання енергії, та імпортозаміщенні енергоресурсів.

Наукова новизна. Установлені причини зменшення рівня релевантності прогнозування та енергетичного плану, необхідного для досягнення ЦСР. Установлено значний рівень кореляції між показником Mtoe та групами індикаторів сталого розвитку та те, що покажчик відносних коливань щодо середнього Mtoe, є інтегральним індикатором досягнення ЦСР.

Практична значимість. Для прогнозування енергоспоживання й моделювання сценаріїв сталого розвитку запропоновано метод MCDA і кількісного підходу до його реалізації.

Ключові слова: *енергетична криза, сталий розвиток, технологічне оновлення, імпортозаміщення енергоресурсів*

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