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IMPACT OF ENERGY INNOVATIONS ON THE UKRAINE'S ECONOMY: STRATEGIC DIRECTION AND MANAGERIAL PRACTICES

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Original Article

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ABSTRACT

Diversification of energy sources and innovative development of the energy sector are one of the main directions for ensuring sustainable development and decarbonization of the economy. The aim of the article is to identify connections and interactions between the parameters of energy innovation development and economic growth. Factor analysis was used for this purpose. The results and conclusions determine the most influential factors among the 5 components identified in accordance with the functional areas of innovative development of the national economy in energetics. The analysis allowed to identify the main trends in the development of factors, which allowed to identify positive and negative changes. The regularities of the influence of certain factors on energy innovations have been determined, which has allowed to provide recommendations for their further development and regulation

Keywords: *energy innovations, multi-factor analysis, decarbonization of the economy..*

1. INTRODUCTION

The issues of ensuring the energy security of Ukraine became especially urgent after the outbreak of the war on February 24, 2022. Global changes in the supply chain, sources of supply, prices, infrastructure of the energy market have made it necessary to quickly develop new approaches for the existence of the energy sector of Ukraine itself. For these purposes, the introduction of energy innovation has become not only an innovative approach, but also the possibility of the existence of the Ukrainian energy sector. The very issue of sustainable development of the economy of Ukraine was raised in the article (Kozlovskyi, 2010), which defines clear vectors for the development of the economy, including the energy sector. The formation of an innovative approach was considered in terms of the introduction of new technologies in the energy sector, as well as in the use of new energy sources (e.g., bio and green technologies).

At the global level, the focus on greening and decarbonization is decisive in the development of the innovation system in the energy sector, which is one of the main tasks of achieving the global goals of sustainable development. Thus, in November 2018, the European Commission presented a long-term strategic concept for reducing greenhouse gas emissions, which defines how Europe can pave the way to a climate-neutral economy with net-zero greenhouse gas emissions by 2050 (EC, 2018; EC, 2020). It contains seven main strategic components: 1) maximization of energy efficiency; 2) maximum implementation of renewable energy sources and electrification; 3) transition to environmentally friendly transport; 4) introduction of circular economy (closed cycle economy); 5) development of "smart" networks and communications; 6) expansion of bioenergy and natural carbon absorption; 7) absorption of the remaining CO2 emissions due to carbon absorption and storage technologies.

As a result of the full-scale military invasion of the Russian Federation in Ukraine on February 24, 2022, and the war that is currently ongoing on the territory of Ukraine, catastrophic changes took place in the socio-economic and other spheres, as well as, among other things, a rapid increase in energy prices, which caused crisis phenomena both in Ukraine and in EU countries.

The geopolitics of energy consumption and energy production is now destabilizing. These challenges only reinforce the need to accelerate the transition to increased renewable energy production and reduced fossil fuel energy consumption. But multiple energy shocks are also driving up production and supply chain costs in energy innovation.

That is why it is important to determine the determinants of the impact on the innovative activity of the energy sector, which will allow to reduce the level of energy import dependence, as well as to form directions for reducing the cost of innovations. For this, the authors conducted an analysis of the impact of energy innovations on the national economy, the difference of which is a comprehensive assessment of the impact of factors and conditions for the development of energy innovations in ensuring the innovative development of the national economy in the energy sector according to five components: 1) productivity of innovative activity; 2) effectiveness of innovation policy; 3) efficiency of energy innovations; 4) investment support for innovative development of the energy sector; 5) development of human capital in terms of decarbonization of the economy.

2. LITERATURE REVIEW

Innovative approaches in different fields of economy are discussed in works (Mićić, Mastilo, 2022; Kresojević et al., 2019; Mešić et al., 2022).

Generalization of scientific works (Shumpeter, 2011; Drucker, 2015; Barnett, 1953; Ilyash et al., 2021), allows to define the innovative development of the national economy as a complex process of restructuring the national economy, achieved through the practical use of new knowledge to increase gross output, improve social quality, improve the competitiveness of the national economy, and accelerate social-economic progress in society. It should be noted that scientists (Grubb et al., 2021; Nemet et al., 2018; Grubler, 2021) emphasize the difference between innovative development in the energy sector from other areas, in particular, the dependence of energy-consuming technologies on energy costs and competition (Butyrskyi et al., 2019) solely on this criterion. Scientists (Lin, Zhu, 2019; Turan, 2020; Brych et al., 2021) argue that the drivers of economic development of the state in terms of energy innovation is the existing innovation potential, which accumulates and is formed taking into account trends in world economies, the dynamics of human capital and exhaustion of natural resources. Numerous studies (Wang, Wang, 2020; Elia et al., 2021; Rubin et al., 2015; Trofymenko et al., 2021; Dluhopolskyi et al., 2021) in the field of energetics have found that the cost of innovative technologies and the speed of their penetration into the market depends on the level of experience and progress of learning in the innovation process.

Chen et al. (2006) describes green innovation as "hardware or software innovation that is related to green products or processes, including the innovation in technologies that are involved in energy saving, pollution prevention, waste recycling, green product designs, or corporate environmental management". It is positioned as the main driver of long-term socio-economic progress. Several studies acknowledged the key factors that affect green innovation adoption, e.g., concerned stakeholders' pressure, strategic orientation, organizational learning, knowledge management, absorptive capacity, and consumers' demands (Song et al., 2020). Further, organizational innovation is a driving force in enhancing industrial export, environmental performance, and, eventually, business excellence (Li et al., 2020). In brief, green innovation inclines to improve competitiveness by developing innovative goods, processes, materials, and institutional frameworks.

Regardless of solutions for physical energy storage, a number of concepts based on virtual substitutes (Oh, 2022) and energy tokenization (Surmann et al., 2022) appear at the level of local energy communities, which are gradually gaining in importance and can be an interesting alternative. The issues of building optimal settlement models (Schreck et al., 2022) and implementing peer-to-peer mechanisms remain invariably problematic for local communities.

It has been proved by Kaletnik et al, 2022, that legal support is an essential component for the development of the bioenergy sector in Ukraine. The experience of leading countries in the sphere of biofuels production show the efficiency of using both penalties and incentives tools.

Under the conditions of Russian invasion in Ukraine the diversification of Ukraine's energy sector is extremely important. Agricultural sector is one of the biggest energy consumers in Ukraine. Pryshliak et al., 2022, have evaluated the potential of agricultural enterprises in terms of producing energy from agricultural residues for ensuring their energy needs. Kaletnik et al, 2021 studied the opportunity of bioenergy production both from agricultural crops and from their residues. Prospects for the production of solid biofuels using such energy crops as Energy poplar (Populus), Switchgrass (Panicumvirgatum), Miscanthus (Miscanthus) has been developed. Also, an integrated logistic model for the production, processing and use of biomass from these bioenergy crops was developed by the authors.

Given the complexity of the research problem, it is obvious that the method of multifactor analysis, due to the simplicity of visualization and interpretation of results by correlating between variables and obtaining fewer factors (Odam, Vries, 2020), has been widely used by various scientists. In particular, in the work (Elia, 2021) – to determine the impact of innovation and technology in renewable energy on the cost of electricity, in research (Bagleri, 2018) – to support energy policy development and planning "green growth". However, despite the large number of scientific achievements in the field of innovation and energy, the issue of methodological approach to the factor analysis of the impact of energy innovations on the development of sectors of the national economy is unresolved, which is the purpose of this work.

3. RESEARCH OBJECTIVES

The study of the impact of energy innovations on the national economy was conducted using factor analysis at the following stages:

1. collection of initial data (BP Statistical review; Global Innovation Index; State Statistics Service of Ukraine) and preparation of the correlation matrix (correlation matrix was used, as the analyzed variables were measured in different units);
2. removal of orthogonal factors or factorization (the principal components method is used);
3. factor rotation (Varimax Rotation method with Kaiser normalization is used) – orthogonal rotation method, which minimizes the number of variables with high loads on each factor, this method simplifies the interpretation of factors;
4. data interpretation.

4. METHODS

Quantitative assessment (Bilenko et al., 2022) of the impact of innovative development in the energy sector on the development of the national economy was conducted using factor analysis using a factor analysis model:

$$X_i = \sum_{j=1}^{m} a_{ij} F_j + U_i \,, \quad (1)$$

where X_i – i-th studied multidimensional feature, a_{ij} – weighting factor of the i-th variable of the j-th factor, F_j – j-th factor, U_i – random variable of the i-th variable (i-th unique factor), m – quantity of factors.

Factor analysis was performed using the program IBM SPSS Statistics 20.0.

In this study, the whole set of features, according to the functional areas of innovative development (Kozlovskyi et al., 2021b) in the energy sector was divided into five components of innovative development of the national economy in the energy sector: Component 1 – innovative activity productiveness; Component 2 – innovation policy effectiveness; Component 3 – energy innovations efficiency; Component 4 – investment support (Kozlovskyi et al., 2021a) for the energy sector innovative development; Component 5 – human capital development in terms of decarbonization of the economy.

The input data for the factor analysis were five matrices of features, rows of which are features, columns are their indicators for the period 2013-2019.

The distribution by components and designations of features (X_{ij}, where i is a component, j is a feature) were formed as follows:

1. Component 1 – innovation productivity: X_{11} – export of high-tech products, % to total exports; X_{12} – R&D private sector expenditures, UAH billion; X_{13} – share of sold innovative products in the total volume of sold industrial products, %; X_{14} – volume of gross value added of industry of Ukraine, %; X_{15} – share of enterprises engaged in innovation in the total number of industrial enterprises, %; X_{16} – share of enterprises that implemented innovations in the total number of industrial enterprises, %; X_{17} – mastered the production of innovative products, units; X_{18} – innovations effectiveness (The Global Innovation Index); X_{19} – implemented new technological processes, units; $X_{1.10}$ – level of production technology, share of GDP in output, %;

2. Component 2 – innovation policy effectiveness: X_{21} – Economic Freedom Index; X_{22} – openness of the economy; X_{23} – size of Ukraine's economy, % of world GDP; X_{24} – level of expenditures on scientific and technical work in GDP, %; X_{25} – public expenditure on research and development, % of GDP; X_{26} – Global Competitiveness Index; X_{27} – innovation activity financing level, % of GDP;

3. Component 3 – energy innovations efficiency: X_{31} – emissions of pollutants and carbon dioxide into the atmosphere by stationary sources, million tons; X_{32} – share of renewable energy consumption, %; X_{33} – renewable energy consumption, million tons of oil equivalent; X_{34} – production of electricity from renewable energy sources, TWh; X_{35} – renewable energy consumption (solar energy), million tons of oil equivalent; X_{36} – production of electricity from renewable energy sources (wind energy), TWh; X_{37} – consumption of renewable energy resources (wind energy), million tons of oil equivalent; X_{38} – production of electricity from renewable energy sources (geothermal resources), biomass (energy raw materials from biomass) and others, TWh; X_{39} – consumption of renewable energy

resources (geothermal resources), biomass (energy raw materials from biomass) and others, million tons of oil equivalent; $X_{3.10}$– total (accumulative) installed capacity of solar photovoltaic energy (at the end of the year), MW; $X_{3.11}$ – total (accumulative) installed capacity of wind turbines (at the end of the year), MW; $X_{3.12}$– total energy production from primary sources (quadrillion BTU – British thermal unit); $X_{3.13}$ – CO2 emissions from natural gas consumption, million metric tons of carbon dioxide; $X_{3.14}$ – CO2 emissions from the consumption of petroleum products (oil), million metric tons of carbon dioxide; $X_{3.15}$– energy intensity – total energy consumption from primary sources per dollar of GDP, MJ per dollar of GDP; $X_{3.16}$– total biofuel consumption, 1000 metric tons; $X_{3.17}$ – installed capacity of renewable energy facilities, MW; $X_{3.18}$ – production of electricity from renewable energy sources (solar energy), TWh;

4. Component 4 – investment support for the energy sector innovative development: X_{41}– share of direct foreign investments in GDP, %; X_{42}– growth of direct foreign investment in GDP, %; X_{43} – investment level, %; X_{44} – integrated index of investment favorable business environment; X_{45}– innovation potential (The Global Innovation Index); X_{46} – GDP per unit of energy consumption, USD at purchasing power parity per kg of oil equivalent; X_{47} – number of licensees who received a "green tariff";

5. Component 5 – human capital development in terms of decarbonization of the economy: X_{51} share of publications with international cooperation in the field of ecology and environment, %; X_{52} – education expenditures level to GDP, %; X_{53} – education level index; X_{54} – rating of the higher education national system; X_{55} – share of scientific and technical work performed in GDP, %; X_{56}– share of specialists performing scientific and technical work, % of the total number of employees; X_{57} – development of technologies and knowledge economy; X_{58} – human capital and research (with direct investment).

5. RESULTS

Within components 1, 3-5 three factors were identified, within component 2 – two (Table 1). The selected factors explain from 87.4% to 93.7% of the total variance, taking into account the fact that the lower threshold value should be at least 70%. The small share of variance (from 6.3% to 12.6%) is due to the influence of features not taken into account in the study. The degree of adequacy of the Kaiser-Mayer-Olkin sample is approximately 0.7, which indicates satisfactory adequacy.
Factor loadings should be understood as correlation coefficients between variables and factors. According to the results of the analysis of the general correlation matrix, those correlation coefficients are selected, the factor loadings of which are the largest within the feature for the respective components.
For Component 1, the dimension is reduced to three factors: the first of them, with a weighting of 0,457, is most affected by features X_{13} (with a correlation coefficient -0,938), X_{16} (0,862), X_{19} (0,838), $X_{1.10}$ (-0,948); on the second, the weighting of which is 0,327, – X_{12} (0,881), X_{14}(0,658), X_{18} (0,942); on the third, the weighting of which is 0,186, – X_{11} (0,942). For Component 2, the dimensionality is reduced to two factors: the first of them, whose weighting factor is 0.631, is most affected by the features X_{21} (with a correlation coefficient -0,859), X_{24} (0,714), X_{26} (-0,98), X_{27} (0,909); on the second, the weighting of which is 0,39, – X_{22} (-0,743), X_{23} (0,991), X_{25} (0,807).
Factor analysis has reduced the dimensionality of Component 3 to the three most influential factors, and the first of them, the weight of which is 0,784, is most affected by featuchers X_{33} (with a correlation coefficient 0,885), X_{34} (0,881), X_{35} (0,916), X_{36} (-0,771), X_{37} (-0,770), $X_{3.10}$ (0,913), $X_{3.11}$ (0,864), $X_{3.14}$ (-0,478), $X_{3.17}$ (0,944), $X_{3.18}$ (0,914); on the second, the weighting of which is 0,153, – X_{38} (0,881), X_{39} (0,658), $X_{3.12}$ (-0,834), $X_{3.13}$ (-0,793), $X_{3.15}$ (-0,889); on the third, the weighting of which is 0,063, – $X_{3.16}$ (0,791).

Table 1. The results of the factor analysis of the innovative development of the national economy in the energy sector.

Factor (component)	Initial eigenvalues		
	total	variance %	cumulative %
Component 1 – innovation productivity			
F_{11}	4,0	40,3	40,3
F_{12}	3,1	31,5	71,8
F_{13}	1,6	16,4	88,2
Component 2 – innovation policy effectiveness			
F_{21}	3,9	55,9	55,9
F_{22}	2,3	33,2	89,1
Component 3 – energy innovations efficiency			
F_{31}	13,2	73,5	73,5
F_{32}	2,6	14,3	87,8
F_{33}	1,1	5,9	93,7
Component 4 – investment support for the energy sector innovative development			
F_{41}	2,9	42,0	42,0
F_{42}	1,7	24,5	66,5
F_{43}	1,5	20,9	87,4
Component 5 – human capital development in terms of decarbonization of the economy			
F_{51}	3,2	39,3	39,3
F_{52}	2,3	28,1	67,4
F_{53}	1,8	22,5	89,9

Source: developed by authors.

Factor analysis has reduced the dimension of Component 4 to the three most influential factors, and the first of them, the weight of which is 0,481, the most influential are the features X_{44} (with a correlation coefficient 0,934), X_{45} (0,916), X_{47} (0,880); on the second, the weighting of which is 0,280, – X_{41} (0,956), X_{42} (0,882); on the third, the weighting of which is 0,239, – X_{43} (0,895), X_{46} (-0,721).

Factor analysis allowed to reduce the dimensionality of the studied Component 5 to the three most influential factors, and the first of them, the weighting coeficient of which is 0,437, is most influenced by the features X_{52}(with a correlation coefficient 0,816), X_{53} (-0,784), X_{58} (0,974); on the second, the weighting of which 0,313, – X_{55} (0,774), X_{56} (0,956); on the third, the weighting of which 0,250, – X_{57} (0,873).

According to the results of the study of the relationship between variables (Table 2) formed a number of key conclusions about the more important factors of Component 1: F_{11}та F_{12}. For the factor F_{11}a greater specific weight have: X_{13}; X_{15}; X_{19}; $X_{1.10}$. Based on the essence of these indicators, this factor F_{11} to a greater extent characterizes the "level of development of innovation-oriented industries". This factor is significantly influenced by two features with correlation coefficients – 0,94 and 0,95, respectively: X_{13}, $X_{1.10}$, which show the specific weight of sold innovative products in the total volume of sold industrial products and the level of production technology. Since these features have a significant impact, but have a correlation coefficient with the sign "minus", this may indicate that they need special attention. Indeed, the level of financing of innovative activities has significantly decreased in 5 years to 0.4% of GDP. The maximum value was observed in 2013, 2015 and 2016 and this value was 0.7%. Note that these features are more influential, but do not have such high numerical values to positively affect the overall factor as a whole. Other important factors with high correlation coefficients, such as X_{16}, $X_{1.10}$, X_{15}, indicate a direct positive effect on the selected factor.

Table 2. Matrix of rotated components of Component 1 - innovation productivity and Component 2 - innovation policy effectiveness.

Feature	**Factor (component)**		
	F_{i1}	F_{i2}	F_{i3}
Component 1 – innovation productivity			
X_{11}	- 0,132	- 0,094	**0,942**
X_{12}	0,257	**0,881**	- 0,032
X_{13}	**- 0,938**	- 0,196	0,011
X_{14}	0,451	**0,658**	- 0,539
X_{16}	0,587	-0,576	0,553
X_{16}	**0,862**	0,008	0,266
X_{17}	0,264	0,047	0,855
X_{18}	- 0,201	**0,942**	0,034
X_{19}	**0,838**	- 0,209	- 0,047
$X_{1.10}$	**- 0,948**	- 0,191	0,034
Share of the feature influence, %	45,7	32,7	18,6
Component 2 – innovation policy effectiveness			
X_{21}	**- 0,859**	0,010	-
X_{22}	0,530	**- 0,743**	-
X_{23}	0,010	**0,991**	-
X_{24}	**0,714**	0,656	-
X_{25}	0,551	**0,807**	-
X_{26}	**- 0,980**	- 0,044	-
X_{27}	**0,909**	0,063	-
Share of the feature influence, %	63,1	36,9	

Source: developed by authors.

In the structure of the factor F_{12} a greater specific weight have: X_{12} ; X_{14}; X_{18}. Based on the essence of the indicators in the composition of this factor, F_{12} characterizes the "effectiveness of innovation activity". The greatest influence with a correlation coefficient of 0.94 on this factor has X_{18}. This indicates the importance of further development of innovation to ensure the growth of the overall factor.

On the factor F_{13} the greatest influence has the indicator X_{11}. Thus, this factor can be described as "the level of development of the export potential of high-tech products". From 2017 to 2019, the share of high-tech products increased to 1.3%, the high-tech potential is increasing. At the same time, the export of high-tech products in relation to the total export has a tendency to decrease, and the maximum share was 8.5% for the studied period in 2015. By 2019, this share decreased by 2%, although the growth of the export of high-tech products refers to the goal of the Export Strategy of Ukraine. It is obvious that the internal market is only gradually expanding and this requires institutional support for the introduction of innovations. Within the component 2, the results of factor analysis revealed two factors. The identified factors explain 89.1% of the total variance. The first factor explains 55.9% of the total variance, the second – 33.2%.

For the factor F_{21} such indicators as X_{21}; X_{26}; X_{27} have a larger specific weight. According to the characteristics of these features (Table 2), this factor F_{21} called "the level of competitiveness of the economy". The greatest influence with a correlation coefficient of -0.98 on this factor has an indicator X_{26}. However, it should be noted that since 2018 the methodology for calculating this index has been changed, as a result, the overall score has increased, but this is not comparable to previous years, also, the new approach involved taking into account aspects of Industry 4.0. Therefore, specifically this indicator in the studied dynamics is not representative of our study. But it can be stated that the growth of this indicator should indicate the high effectiveness of innovation policy. The second most important indicator is X_{27} (correlation coefficient 0,91). Thus, adequate funding will increase the competitiveness of the economy. And in third place in terms of influence is the indicator X_{21}. This indicator varies in its values over the study period. This may explain the inverse correlation determined by the analysis, ie in the aggregate of indicators it does not directly affect the growth of the factor. However, this indicator testifies, in particular, to the freedom of business and investment. Its growth will determine the effectiveness of innovation policy, because the support of start-up projects and small and medium-sized businesses is a prerequisite for the development of innovation (Ilyash et al., 2021).

In the structure of the factor F_{22} in Component 2 a greater specific weight have X_{22}; X_{23}; X_{24}; X_{25}. This factor can be summarized as "the level of economic activity in innovation". The greatest influence on this factor has X_{23}. That is, the size of Ukraine's economy is decisive for the level of economic activity. Within component 3 "energy innovations efficiency" three factors were identified. The identified factors explain 93.2% of the total variance. The first factor F_{31} explains 73.5% of the total variance, the second F_{32}– 14.3%, third F_{33}– 5.9%. Therefore, the most significant for the study is F_{31}. Thus, to F_{31} of Component 3 includes the following features with the largest specific weight: X_{33}; X_{34}; X_{35}; X_{36}; X_{37}; $X_{3.10}$; $X_{3.11}$; $X_{3.14}$; $X_{3.17}$; $X_{3.18}$. According to these features (Table 3), this factor can be described as "the level of renewable energy development". The greatest influence on this factor is exerted by the feature $X_{3.17}$, however, it is the only one in the set of factors with a negative correlation coefficient. This may indicate that the installed capacity is not always proportional to the level of electricity generation and there are problems with their commissioning. In addition, an indicator $X_{3.14}$with a negative correlation index was determined. Indeed, a decrease in this indicator will shows an increase in the level of development of renewable and alternative energy, as the most environmentally friendly, which will increase the level of decarbonization of the economy. Influential and close to the values of the correlation coefficient are other listed features of this factor, they all have a positive effect on this factor. That is, with increasing production and consumption of electricity from renewable sources, the level of development of renewable and alternative energy increases.

Table 3. Matrix of rotated components of Component 3 – energy innovations efficiency.

Component 3 – energy innovations efficiency			
X_{31}	- 0,172	**- 0,884**	- 0,366
X_{32}	0,376	**0,893**	- 0,057
X_{33}	**0,885**	0,435	0,150
X_{34}	**0,881**	0,441	0,162
X_{35}	**0,916**	0,396	0,026
X_{36}	**0,771**	0,425	0,466
X_{37}	**0,770**	0,409	0,481
X_{38}	0,414	**0,883**	0,111
X_{39}	0,408	**0,884**	0,113
$X_{3.10}$	**0,913**	0,394	0,091
$X_{3.11}$	**0,864**	0,438	0,225
$X_{3.12}$	- 0,346	**- 0,834**	- 0,364
$X_{3.13}$	- 0,344	**- 0,793**	- 0,405
$X_{3.14}$	**- 0,478**	0,393	- 0,406
$X_{3.15}$	- 0,421	**- 0,889**	- 0,131
$X_{3.16}$	0,045	0,427	**0,791**
$X_{3.17}$	**- 0,944**	- 0,070	- 0,045
$X_{3.18}$	**0,914**	0,400	0,028
Share of the feature influence, %	78,4	15,3	6,3

Source: developed by authors.

The second factor of Component 3 has not a high value of variance – up to 15%. In the structure of the second factor F_{32} of Component 3, have a greater specific weight such features as: X_{31}; X_{32}; X_{38}; X_{39}; $X_{3.12}$; $X_{3.13}$; $X_{3.15}$. According to these main features, this factor can be described as "the level of effectiveness of decarbonization measures".

The third factor of Component 3 is explained by the variance of not more than 6%, so we do not take it into account.

Table 4. Matrix of rotated components of Component 4 – investment support for the energy sector innovative development.

Component 4 – investment support for the energy sector innovative development			
X_{41}	- 0,156	**0,956**	0,162
X_{42}	0,326	**0,882**	- 0,194
X_{43}	- 0,183	- 0,108	**0,895**
X_{44}	**0,934**	0,131	- 0,167
X_{45}	**0,916**	0,081	0,002
X_{46}	- 0,407	- 0,153	**- 0,721**
X_{47}	**0,880**	- 0,081	0,360
Share of the feature influence, %	48,1	28,0	23,9

Source: developed by authors.

In the Component 4 – "investment support for the energy sector innovative development" as a result of the analysis, three factors were identified, which are explained by the total variance 87.4% (Table 4). The more important features of the first factor are: X_{44}; X_{45}; X_{47}. Therefore, this factor can be described as "the level of innovation and investment potential in the field of renewable energy". The greatest influence on this factor have the features X_{44} (with a correlation coefficient 0,93) and X_{45}(with a correlation coefficient 0,92).

In the structure of the second factor, the most important features were identified as: X_{41}; X_{42}. Therefore, this factor can be described as "the level of investment".

In the structure of the third factor of Component 4, two important factors were identified: X_{43}; X_{46}. This factor can be called "the level of investment per unit of energy consumed".

In the structure of Component 5 – "human capital development in terms of decarbonization of the economy" in the first factor F_{51} have identified such more significant features as: X_{52}; X_{53}; X_{58} (Table 5). Thus, this factor can be described as "the population education level".

The most influential factor with a correlation coefficient of 0,97 – X_{58}. So, with increasing values X_{58} the general level of education of the population increases. At the same time, the indicato X_{53} has an inverse correlation, which can be explained by the fact that in Ukraine in the studied period the problem of migration became acute.

In the structure of the second factor F_{52} features have a greater specific weight X_{51}; X_{55} and X_{56}. Based on the essence of these features, it is appropriate to call the factor – "the level of involvement of specialists in innovation activities". The greatest influence on this factor has the feature – X_{56}. Thus, the more specialists, the greater the level of realization of scientific and technical potential. At the same time, it is worth paying attention to the indicator X_{51}, which has a correlation coefficient – 0.8. This feature has an inverse effect on the selected factor and may indicate that the number of publications does not mean the quality of research or that some publications are not of practical importance and therefore do not have a direct impact on the factor level of scientific and technological potential, or that science in Ukraine is separated from practice (Ilyash et al., 2021).

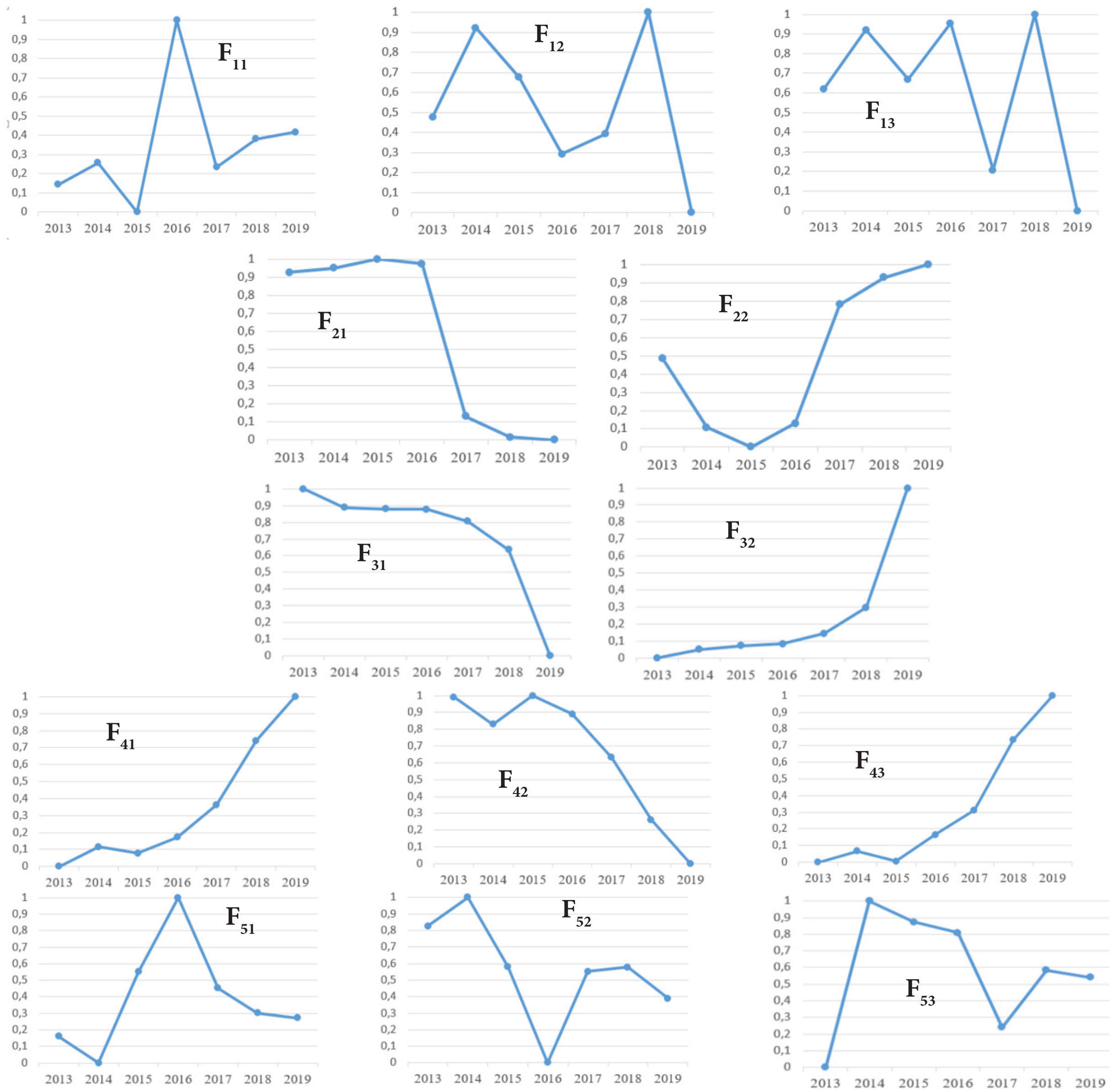
Table 5. Matrix of rotated components of Component 5 – human capital development in terms of decarbonization of the economy.

Component 5 – human capital development in terms of decarbonization of the economy			
X_{51}	0,550	**- 0,801**	0,043
X_{52}	**0,816**	0,378	0,410
X_{53}	**- 0,784**	- 0,079	0,403
X_{54}	- 0,269	0,258	- 0,856
X_{55}	0,439	**0,774**	- 0,268
X_{56}	0,212	**0,956**	0,040
X_{57}	- 0,272	0,083	**0,873**
X_{58}	**0,974**	0,018	0,018
Share of the feature influence, %	43,7	31,3	25,0

Source: developed by authors.

In the structure of the second factor F_{53}, which is explained by 22% of the variation, features have a greater specific weight X_{54}; X_{57}. Thus, this factor can be described as "the realization of educational potential in the knowledge economy".
The identified factors normalized and visually presented the trends of each identified factor of the studied component (Figure 1).
Analysis of the factors values dynamics suggests that the factors F_{11} and F_{13} are complementary, because the level of development of innovation-oriented industries together with the level of development of export potential determines the level of efficiency of innovation activity (Ilyash et al., 2022). However, a pattern is found that with the growth of factors F_{11} and F_{13} factor F_{12} increases significantly, but low levels of both factors F_{11} and F_{13} significantly and in the long run cause a drop in the level of efficiency F_{12} not for 1 year, as can be logically found, but for 2 years. After such a occurrence (stagnation, in our case two years) causes the socio-economic system to recover through the efforts of simultaneous positive impact F_{11} and F_{13}.
The dynamics of the second factor "innovation activity effectiveness" is interesting, because it shows the opposite trend when compared to the first factor. Thus, from 2013 to 2018, the indicator fluctuated with an increase to the maximum value in 2018 and a decrease in 2019 to a critical value. This factor is most influenced by indicators X_{12}, which are usually insignificant, X_{14}, which has grown significantly since 2015, and X_{18}, in particular, in the field of defense-industrial complex, where there was a significant segment of private investment (League of Defense Enterprises) in the development and production of equipment. The decline of the indicator in 2019 may evidence a decline in industrial activity due to the pandemic, and a change in the priorities of enterprise expenditures.

Figure 1. Trends in the development of impact factors of energy innovations on the national economy within identified components.



Source: developed by authors.

If we compare the trends of factors, F_{21} and F_{22} (Figure 1), we can see that they are inverted. This can be explained by the fact that the level of Ukraine's competitiveness relatively to other countries is low, and with the development of relations at the global level, these indicators are changing in all countries in homogeneously. Therefore, the values for an individual country by years may not be comparable. At the same time, trends in the importance of the factor of economic activity in the field of innovation indicate that with the decline of the first factor of competitiveness, economic activity in the field of innovation increased.

Proceeding from dynamics of factors F_{31} and F_{32} of Component 3, they have an inverse tendency compared to each other. The level of development of renewable energy has tended to decrease, especially the sharp decline occurred from 2018 to 2019. And vice versa, a factor F_{32} gradually grew and from 2018 to 2019 there was a rapid growth. This can be explained by the fact that, in general, the energy intensity of production decreased, which, in turn, reduced the need to use the traditional fuels. At the same time, the decline in industrial production due to some downtime in 2019 due to COVID-19 (Petrunenko et al., 2022) also contributed to the growth of decarbonization.

Factors F_{41}, F_{42} and F_{43} have the greatest impact on Component 4. It can be seen that F_{41} "the innovation and investment potential level in the field of renewable energy" and F_{43} "the level of investment per unit of energy consumption" have similar growth trends over the period. At the same time, F_{42} "the foreign investment level" has the opposite tendency to the above factors – to decrease.

Figure 1 shows that there are opposite trends in the values of indicators for F_{52} "the level of involvement of specialists in innovation activities", F_{53} "realization of educational potential in the knowledge economy" and F_{51} "the population education level". This is explained by the direct influence of such a logical chain: the population education level in fact raises the educational potential, the realization of which is required in the economy, because highly qualified personnel are already formed by the education of the population. Public awareness of the need for decarbonization of industry acquires features of social responsibility in the long-term educational process which in general raises the educational, scientific, innovative levels of a particular country, and the conscious society sets before the government the goal - to improve the quality of life by reducing harmful emissions. That is why it can be argued that the knowledge economy, which is widespread in the so-called smart countries, leads to the fact that society puts first the quality and safety of life.

6. DISCUSSION

Today, as a result of the Russian Federation's full-scale military invasion of Ukraine, the global energy market is transforming and needs to further expand energy innovation to meet the energy needs of a number of countries that have imposed sanctions on Russia today. The European Commission has announced a preliminary REPowerEU plan to end Europe's dependence on Russian fossil fuels by 2030 (Repowereu: Affordable, secure and Sustainable Energy for Europe, 2022). Some member states have proposed banning energy imports from Russia. Other countries, in particular Germany, are not ready to give up completely, given the high level of dependence on these imports, which indicates the unwillingness to make a rapid energy transition. The Baltic states were the first countries in Europe to stop importing Russian gas. From April 1, 2022, Russian natural gas no longer flows to Latvia, Estonia and Lithuania. Poland plans to take decisive action, seeking to completely stop imports of Russian oil, gas and coal by the end of 2022. In support of Ukraine and opposition to russian armed aggression, EU leaders adopted the Versailles Declaration (The Versailles Declaration, 2022). Taking into account the EU's goal of climate neutrality by 2050 and to ensure security of energy supply, it was agreed to stop the import of Russian energy resources as soon as possible, in particular by introducing a number of measures to develop energy innovations. All this reveal to the forthcoming rapid innovative path of energy, which was prompted, in particular, by the war in Ukraine. On the one hand, for Ukraine today the main priority is to improve the defense industry to protect the state, on the other – ensuring the independence of Ukraine's energy sector through innovation by reducing the consumption of imported traditional energy sources is a contributing factor to the whole economy.

7. CONCLUSION

The scientific novelty of the study is the implementation of a comprehensive approach to analyzing the impact of energy innovations on the national economy, the difference of which is a detailed and comprehensive assessment of the impact of factors and conditions for the development of energy innovations in ensuring the innovative development of the national economy in the energy sector according to five components.

Thus, in order to identify the connections and interactions between the parameters of the development of energy innovations and the economic growth of the state, a multifactor analysis was used, which included 50 indicators, which collectively reveal such aspects as (1) the productivity of innovative activities, (2) the effectiveness of innovation policy, (3) efficiency of energy innovations, (4) investment support for innovative development of the energy sector, (5) development of human capital in the decarbonization of the economy. As a result, a significant positive impact of the activation and improvement of the efficiency of energy innovations on economic growth has been proven. The selected factors explain from 87.4% to 93.7% of the total variance, taking into account the fact that the lower threshold value should be at least 70%. A small share of the variance (from 6.3% to 12.6%) is explained by the influence of features not taken into account in the study. The measure of adequacy of the Kaiser-Meier-Olkin sample is approximately equal to 0.7, which indicates satisfactory adequacy. Accordingly, this methodical approach can be applied to predict the effectiveness of state policy in the analyzed area.

The analysis allowed to identify the main factors and trends in their development, as well as to identify positive and negative changes in the development of Ukraine's economy to ensure innovative development of the energy sector. It is necessary to create preconditions for increasing the development of renewable energy and to stimulate energy innovations to reduce harmful emissions and increase energy efficiency, then it will have a positive impact on the efficiency of energy innovation. It should be noted that such prerequisites are the relevant state support, which is now reflected in global programs for the energy sector development. In the context of the war in Ukraine, in addition to measures to strengthen the defense industry, ensuring the independence of the energy sector in Ukraine and globally is an important lever to combat the aggressor. It is advisable to take into account the analyzed factors and areas of their further regulation, which will accelerate the development of energy innovation in Ukraine.

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