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Ecological and economic effects of industrial and technological development

O Ilyash[1,2], O Trofymenko[2], I Dzhadan[3] and T Tsarova[3]

[1] Department of Economic Cybernetics, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", 37 Victory avenue, building 1, Kyiv 03056, Ukraine
[2] International University of Finance, 37 Victory avenue, building 1, Kyiv 03056, Ukraine
[3] Department of Industrial Marketing, National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", 37 Victory avenue, building 1, Kyiv 03056, Ukraine

E-mail: oliai@meta.ua

Abstract. The article is devoted to topical issues of mutual influences of ecological and economic, industrial and technological development. The main purpose of the article is to study the system characteristics of the relationship between industrial and technological development and the effectiveness of the national economy. Such a relationship is based on the policy of environmental innovation, which is implemented at the junction of relations in the fields of environmental safety, industrial policy and technological development of Ukraine. The article aims to determine economic effects of the ecological component of industrial and technological development of the country. The study found that the industrial and technological growth of the national economy depends to a large extent on the ecological component. The method of taxonomy was used to carry out an integral assessment of ecological indicators of industrial and technological development in the system of ecological and economic security of Ukraine. The application of tools of multidimensional statistical analysis, the harmonization of indicators of industrial and technological development and ecological and economic security of Ukraine helped to determine the economic effects of ecological impact.

1. Introduction

According to the economic classification of the International Monetary Fund, Ukraine today is part of European developing countries (Emerging and Developing Europe). Relations between Ukraine and the European Union are maintained due to a political union and economic integration, which creates favourable conditions for economic growth and development of industrial technologies and environmental innovation. However, the commitments made in preparation for the voluntary national review of Sustainable Development Goals 7, 9 and 17 for the next ten years require monitoring the progress of technological innovation in Ukraine and analysis of the environmental policy on industrial development in the short term.

In the context of economic changes and transformations associated with the formation of Industry 4.0, 5.0, the Ukrainian government continues to refine the strategy for developing the industrial complex until 2025.

According to the chosen direction of EU integration, the strategy should take into account the fact that by 2050 Europe will become climate neutral. The indicators of the achievement of the 17 sustainable development goals by 2030, approved by the UN Summit on Sustainable Development in 2015, were also formulated at the national level [1], including goals 7, 8, 9, 12, which are aimed at conserving resources, developing environmental technologies and reducing the negative impact of industrial and technological development on the environment. On 18 June 2020, the European Commission approved the adoption of the Taxonomy Regulation, which is a key piece of legislation that will facilitate the conclusion of a European «green deal» by stimulating innovative industrial policies in the field of «green» and sustainable development [20] All this raises the issue of monitoring the dynamics of ecological effects of industrial and technological development in the processes of long-term sustainable development of the national economy.

2. Literature Review

On the one hand, the symbiosis of scientific achievements O. Ilyash, R. Lupak, T. Vasyltsiv [2, 3] quite naturally justifies the expediency of studying the economic cycles of the socio-economic system in terms of technological modes, energy innovation and formalises the multifunctionality of innovative development. On the other hand, it complicates applied analysis of ecological effects of industrial and technological development [4]. In this context, it is reasonable to highlight the scientific work of O. Vlasiuk [5] and A. Mokiy, Y. Pynda et al. and others [6,7], who argue that the state of civilisation is determined by the parameters of innovative development of many problems, including the development of industries. Therefore, innovative development is a fundamental basis of economic and ecological security in support of sustainable development processes. Such scientists as V. Horbulin, A. Prokip, V. Barranik, L. Chester, K. Kok and S. Karlsson-Vinkhuyzen, N. Jollands, V. Koval [8, 9] should also be mentioned as ideologues of the concept of ecological and energy security of the state. Recent studies by V. Detlef, S. Busch, J. Leininger, D. Biermann, F. Kanie, R. Kim, O, Kubatko, L. Melnyk, E. Mikelsone [10- 12] focus on innovative mechanisms for achieving sustainable development goals, but no studies show the results of monitoring simultaneous or long-term consequences of the impact of environmental innovation on the process of sustainable planning of industrial and technological development.

At the same time, in their scientific work, S. Scharl and A. Praktiknjo [13] mention such aspects in the context of research of innovative development of the environment in the conditions of Industries 4.0, 5.0. The scientists claim that a growing influence of the role of the digital Industry 4.0 on the processes of developing the «green» economy implies a total increase in the efficiency of energy development of the economy, including industry. Actually, the main provisions of modern research on innovative development of the national economy by D. Kurbatov and O. Prokopenko [14], S. Voitko, O. Trofymenko, T. Pavlenco [15] are based on the ideas of creating innovative mechanisms for industrial and technological growth of the national economy using alternative energy methods. F. Hackstein and R. Madlener [16] emphasise the need to use such innovative ecological technologies as geothermal resources for electricity production, which is the basis for sustainable development of each country. For example, a famous scientist P. Borowski [17] proposes using energy innovations as ecological innovations, e.g. virtual dynamic simulation energy models Digital-Twins.

In addition, given a real threat of climate change, the strategic role of the Smart Grid concept of industrial development is growing, since it enhances the economic effects of industrial and technological development and restrains the impact of ecological challenges. That is why energy innovations and the mechanisms of their use in industry are necessary due to the need to decarbonise industry, which is confirmed by the scientific paradigm of change in the vector of research of C. Wilson, A. Grubler, N. Bento and others [18], J. Kikstra, A. Mastrucci, M. Jihoon [19]. The authors O. Trofymenko, O. Shevchuk, N. Koba et. al [20] convincingly prove the need for introducing systemic industrial and technological, ecological innovations, launching «Transition Super Laboratories», initiatives to manage the processes of decarbonisation of the economy, associated with the transition from typical local industrial economies based on fossil fuels to carbon-free technologies.

3. Methods

To compare ecological indicators of industrial and technological development of national economies around the world, the main indicators [21] were chosen. Such indicators as the environmental performance index [22], total greenhouse gas emissions per 1,000 dollars of GDP, the environmental protection index, the ecosystem vitality index, the share of renewable energy consumption and existing agreements related to the environment [23] provide an opportunity to assess ecological progress of the national economy.

Technologically developed countries, countries with a high level of GDP and Ukraine were selected to make a comparison between these indicators. We believe that the environmental performance index is one of the most important indicators of ecological progress of the national economy, which defines two main aspects of sustainable development: ecological health, which improves with economic growth and prosperity, the vitality of ecosystems under industrialization and urbanization. This index also includes the environmental protection index and the ecosystem vitality index.

The analytical component of the article helps to monitor the current state of the ecological component of industrial and technological development and identify effects/ risks that reduce the level of ecological and economic security of the country. Therefore, multidimensional analysis of the ecological indicators of industrial and technological development will be conducted.

To assess the factor impact and determine the economic effects of the relationship between industrial and technological development and the ecological indicators of the state security, a system of indicators was formed. It includes (1) capital investment in environmental protection (UAH in GDP, %); (2) emissions of pollutants and carbon dioxide into the atmosphere by stationary sources (million tons); (3) the share of renewable energy consumption (%); the share of publications involving international cooperation in the field of ecology and the environment (%).

The method of taxonomy was used to determine the largest number of features that will affect the object of the study [24]. The information base for the use of taxonomic analysis are indicators of the ecological component of ensuring industrial and technological development of Ukraine during 2013 - 2019.

To carry out the taxonomic analysis, the algorithm of the following actions was performed: (1) a matrix of initial data for the study X(M3) was formed. The matrix reveals the ecological component of industrial and technological development (size 4×7 and standardised values of the matrix of indicators Y (M5), by means of standardising the indicators according to formula 1:

$$Z_i = \frac{I_i}{\overline{I}}, \tag{1}$$

where: I_i – the value of the i-th indicator; $\overline{I}$ – the average value of the indicator;

$$X^{(M3)} = \begin{bmatrix} 0,04 & 0,05 & 0,04 & 0,06 & 0,04 & 0,03 & 0,04 \\ 197,6 & 166,9 & 138,9 & 150,6 & 124,2 & 126,4 & 121,2 \\ 2,70 & 2,60 & 3,00 & 3,80 & 4,40 & 4,60 & 4,90 \\ 10,08 & 7,79 & 13,49 & 21,09 & 13,49 & 14,09 & - \end{bmatrix}, \tag{2}$$

$$X^{(M5)} = \begin{bmatrix} 1,348 & 1,156 & 1,059 & 0,925 & 0,867 & 0,905 & 0,828 \\ 1,620 & 1,266 & 1,013 & 0,810 & 0,810 & 0,861 & 0,861 \\ 1,234 & 1,050 & 1,050 & 1,050 & 1,050 & 0,788 & 0,788 \\ 1,244 & 1,166 & 1,166 & 0,933 & 0,902 & 0,839 & 0,746 \\ 0,577 & 1,152 & 0,689 & 0,875 & 1,175 & 1,341 & 0,961 \\ 1,061 & 1,052 & 0,950 & 0,993 & 0,976 & 1,001 & 0,993 \end{bmatrix}, \tag{3}$$

After standardising the indicators, the features of observation matrices are divided into stimulators and destimulators, which determine the direction of the impact of the ecological indicators on industrial and technological development. Virtually all selected indicators are stimulators, except for the share of the leading partner country in total exports of goods and emissions of pollutants and carbon dioxide into the atmosphere by stationary sources. The division of the features into stimulators and destimulators is the basis for finding the ideal vector-standard and forming the values of marketing indicators in the following way (formula 4):

$$\begin{cases} I_{oi} = \max I_{ij}(stimulator) \\ I_{oi} = \min I_{ij}(destimulator) \end{cases}, \quad (4)$$

The vector-standard of the level of ecological support of industrial and technological development is obtained: E(M3) = (1.385; -0.839; 1.324; 1543 and the elements of the matrix of distances to the point of the upper pole (P0) are calculated by formula 5:

$$C_{io} = \sqrt{\sum_{i=1}^{m} (I_{ij} - I_{0j})^2}, i = 1,...,m \quad (5)$$

where I_{ij} – standardised value of the j-th indicator in the period of time i; I_{0j} – standardised value of the i-th indicator in the standard.

The obtained distance is initial for defining the indicator of ecological support of industrial and technological development, which is calculated by formulas 6, 7:

$$K = 1 - d \quad (6)$$

where d – the deviation of the distance between the point with the figure of one and the point (P_0) from the value of the distance of the features:

$$d_i = \frac{C_{i0}}{C_0} \quad (7)$$

where C_{i0} – the distance between the point with the figure of one and the point P_0; C_0 – distance.

In addition, our study is focused on substantiating the relationship between the indicators of ecological and economic security and the indicators of ecological support of industrial and technological development. To analyse this relationship, it is necessary to calculate the Pearson correlation coefficient.

$$r = \frac{(N - \overline{N}) \cdot (Y - \overline{Y})}{\sqrt{(N - \overline{N})^2 \cdot (Y - \overline{Y})^2}} \quad (8)$$

where r – the Pearson correlation coefficient; N – ecological indicators; Y – the level of ecological and economic security.

The Pearson correlation coefficient can take values in the range from -1 to 1; a positive value reflects the growth of Y due to the growth of I_n, and a negative value means a decrease of Y due to the growth of I_n. It should be added that if the coefficient is close to zero, it indicates that there is no relationship between the categories. Interpretation of the correlation coefficient is based on the level of the strength of the relationship: a weak positive relatioship (r ≥ 0.1 ≤ 0.3), a medium positive relationship (r ≥ 0.3 ≤ 0.5), a strong positive relationship (r ≥ 0.5 ≤ 1.0), a weak negative relationship (r ≥ -0.1 ≤ -0.3), a medium negative relationship (r ≥ -0.3 ≤ -0.5), a strong negative relationship (r ≥ -0.5 ≤ -1.0)) [25]

To make a forecast of industrial and technological development in the system of ecological and economic security, we use the method of exponential Holt smoothing. In the proposed algorithm, the values of the level and trend are smoothed using exponential smoothing, and the smoothing parameters are different (Formula 9) [26]:

$$\begin{cases} \Omega_t = \alpha \cdot Y_1 + (1-\alpha) \cdot (\Omega_{t-1} - T_{t-1}) \\ T_t = \beta \cdot (Q_1 - Q_{t-1}) + (1-\beta) \cdot T_{t-1}, \\ Y_{t+p} = \Omega_1 + p \cdot T_1 \end{cases} \quad (9)$$

where Ω_t – the forecast value for the current time, T_t– determination of the trend of values; Y_t – the value of the time series; Y_{t+p} – the forecast value for t periods in the future.

Hence, the presented theoretical and methodological model for assessing the ecological component of industrial and technological development in the system of economic security involves a comprehensive diagnosis of the level of individual indicators using different research methods. It should be noted that the choice of a particular method of assessment depends on the accurate and reasonable definition of measurements and standards of evaluation, which is based on a detailed assessment of industrial and technological development of the country.

4. Results

Security-oriented industrial and technological development in the conditions of Industries 4.0, 5.0 is a key condition for sustainable development of the national economy. Therefore, if there are not enough funds for an innovative environmental policy, this cannot be achieved. To illustrate, investments in environmental protection capital amounted to only 0.04% of GDP in 2019 (16.2 billion UAH). Investments were mainly used for waste disposal (35.4%); air protection and climate change (26.3%); radiation safety (15.2%); protection and restoration of soil, groundwater and surface water (10.6%). Industry constituted a significant part of the structure of capital investment in 2019 (38.9%). Furthermore, during the period under study, there were positive changes in the financing for industrial measures to protect the environment, especially in 2019 compared to 2013, because the volume of capital investment increased by 2.7 times. It is worth mentioning that EU countries allocate about 2% of GDP for environmental protection. The ecological effects of industrial and technological development can be enhanced by reducing greenhouse gas emissions, implementing programmes to preserve the environment and the vitality of ecosystems, increasing the consumption of renewable energy. For example, by the environmental performance index, Ukraine was ranked 109th among 180 countries in 2019. With a score of 52.87, Ukraine was between Turkey (108th place) and Guatemala (110th place). At the same time, the highest levels of environmental performance were observed in Switzerland, Denmark (81.60), Finland (78.64), Germany (78.37) and Japan (74.69).

Table 1. The indicators representing the ecological component of industrial and technological development.

Indicators	**Years**							**Growth rates, %**		
	2013	2014	2015	2016	2017	2018	2019	2019/ 2018	2019/ 2015	2019/ 2013
1. Capital investments in environmental protection UAH in GDP, %	0.04	0.05	0.04	0.06	0.04	0.03	0.04	133.33	100.00	100.00
2. Emissions of pollutants and carbon dioxide into the atmosphere by stationary sources, mill. tons	197.6	166.9	138.9	150.6	124.2	126.4	121.2	95.89	87.26	61.34
3. The share of renewable energy consumption, %	2.70	2.60	3.00	3.80	4.40	4.60	4.90	106.52	163.33	181.48
4. The share of publications involving international cooperation in the field of ecology and the environment	10.08	7.79	13.49	21.09	13.49	14.09	n.d.	-	-	-

Source: compiled and calculated by the authors based on [23, 27].

Today Ukraine experiences a negative trend in all groups of the indicators that characterise the environment, except for water resources and fisheries. Ukraine lost 49.9 points in the category's climate change and energy. This indicator shows a marked increase in the level of carbon emissions per unit of GDP. In terms of air quality and the level of its pollution with hazardous substances, Ukraine lost 20 points. It lost 26.3 points in the category of water quality and sanitation, 33 points – in the category of forests and 16.5 points – in the category of environmental protection and biological diversity [28].

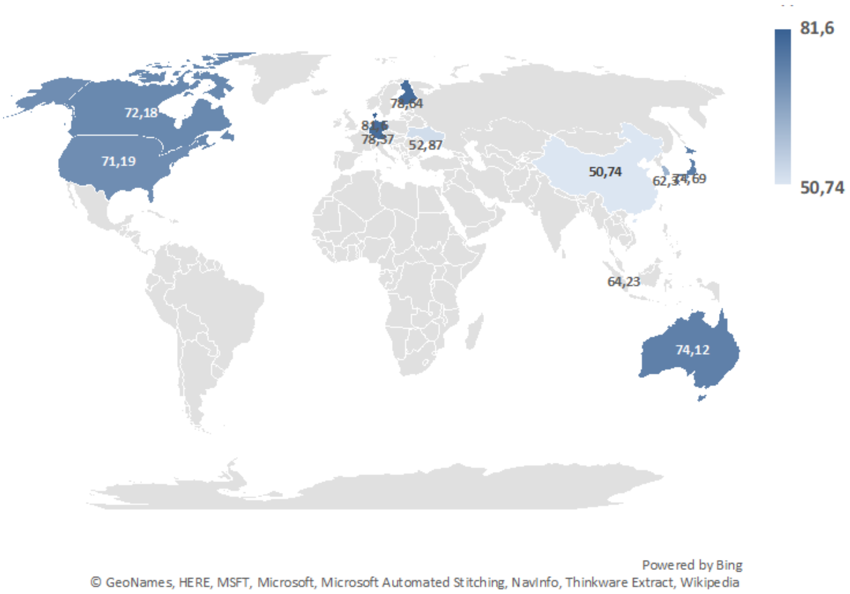


Figure 1. Environmental Performance Index of the National economy (EO).

Source: formed by the authors based on [22]

The environmental protection index as one of the indicators of Ukraine's ecological progress in 2019 was only 64.44, which is 54-60% lower than that in Finland (99.35), Denmark (98.20) and Australia (97.95). It was conditioned by a high level of employing resource-intensive and energy-intensive technologies, which were implemented and exploited without the construction of appropriate waste treatment facilities and without taking into account the requirements of environmental protection. High indicators of total emissions of «greenhouse» gases point to the unsustainable development of industry [6]. Experts believe that if 158 countries, which are responsible for 94% of greenhouse gas emissions meet their obligations, it will limit a global temperature rise by about 2.7°C by 2100. However, Ukraine is among the 15 countries with an "inadequate" contribution to the limit of a temperature rise within 2°C, and Ukraine's emissions will continue to increase by 42% from the level observed in 2019 to 2030. At the same time, China, Korea, Canada, Australia and the United States accounted for 70.36% of total CO_2 emissions per GDP per 1,000 dollars and amounted to 2.97 tons of CO2/1,000 dollars in 2019 [2]. The development of renewable energy is one of the priority areas that will help to reduce greenhouse gas emissions and is one of the targets of Goal 7 "Ensure access to affordable, reliable, sustainable and modern energy for all" of the Sustainable Development Goals adopted at the UN Summit in 2015 [1]. In Ukraine, the share of renewable energy consumption in 2019 was only 0.5%, while in developed countries it could be from 6 to 55%. Sweden, Finland and Denmark are among the world's progressive economies in the field of renewable energy.

The calculations of the taxonomic indicators of ecological support of industrial and technological development in the system of economic security in 2013-2019 are given in Table 2.

Table 2. The taxonomic indicator of ecological support of industrial and technological development in the system of ecological and economic security.

The support component	Indicators	Years							Indicators
		2013	2014	2015	2016	2017	2018	2019	
Ecological component (M3)	$C_{i0}^{(3)}$	1,223	1,219	0,895	0,360	0,735	0,866	0,689	$\overline{C_0}$= 0,855
	$d_i^{(3)}$	0,862	0,859	0,631	0,254	0,518	0,610	0,486	S_0= 0,282
	$K_i^{(3)}$	0,138	0,141	0,369	0,746	0,482	0,390	0,514	C_0=1,419

Source: compiled and calculated by the authors based on [1].

In the dynamics of the ecological component of industrial and technological development one can observe steady growth, which is brought about by increased capital investment in environmental protection, reduced emissions of pollutants from stationary sources, changes in the environmental tax rate, the introduction of a green tariff. For instance, in 2019, the value of the taxonomic indicator was 0.514, which is almost 4 times higher than in 2013. In general, the dynamics of the taxonomic indicator of ensuring industrial and technological development of Ukraine in the system of economic security during 2013-2019 was «wave-like», reaching the highest value in 2013 (0.696) and in 2019 (0.695). The taxonomic analysis of the ecological component of ensuring industrial and technological development showed that if changes are taken into account and responded to in a timely fashion, it will enable the state to adopt an effective environmental and industrial policy, thereby preventing risks to economic and ecological security.

In the process of calculating the linear correlation coefficient of marketing support indicators and the level of economic security, the obtained values made it possible to single out four groups of indicators depending on the closeness of the relationship.

Table 3. The coefficients of the closeness of the relationship and the results of variance analysis of the ecological indicators of industrial and technological development and the level of ecological and economic security of the state.

The support component	Indicators	Coefficient of correlation (r)	Coefficient of determination (R^2)	Indicators	Coefficient of correlation (r)	Coefficient of determination (R^2)
Ecological component (M)	N_1	0.05848	-0.1298	N_5	0.01074	-0.1871
	N_2	0.005205	-0.1938	N_6	0.01813	-0.1782
	N_3	0.3759	0.2511	N_6	0.7047	0.6457
	N_4	0.08206	-0.1015	N_7	0.3206	0.1847

Source: compiled and calculated by the authors based on [23].

A medium correlation was found with the share of renewable energy consumption (N1), the volume of gross value added of industry (N2), the global competitiveness index (N3).

A weak correlation is observed for the level of funding for innovation; innovation potential and the number of mastered production of innovative types of products; the introduction of new technological processes. At the same time, there is no correlation with capital investment in environmental protection, UAH in GDP; emissions of pollutants and carbon dioxide into the atmosphere by stationary sources; the share of publications involving international cooperation in the field of ecology and the environment; the volume of sold industrial products; the share of sold innovative products in the total volume of sold industrial products; the level of production technologies (the share of GDP in output).

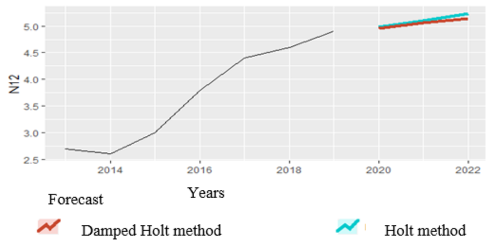
As there are many variables to represent the results of calculating the pairwise correlation of variables, we chose a special method of displaying correlations – a correlation map using the corrplot function of the programming language R. To form a correlation map, the component of economic and ecological security (Y) will be an independent variable and separate indicators of ensuring industrial and technological development with high and medium values of the correlation coefficient for 2013-2019 will be an independent variable. These indicators form the information base and they are presented in Table 4.

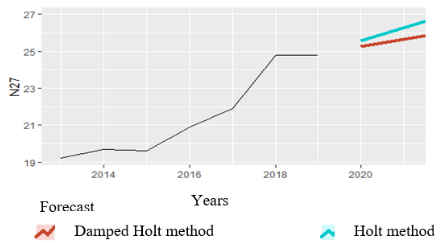
Table 4. The results of forecasting industrial and technological development in terms of separate indicators with a medium correlation for the period up to 2022.

Years	The share of renewable energy consumption N1		The volume of gross value added of industry N2		The global competitiveness index N3	
	Holt's method	Holt's method	Holt's method	Holt's method	Holt's method	Holt's damped method
2020	4.977530	25.55449	61.99044	61.99044	0.4331471	0.4585804
2021	5.104337	26.26389	66.41395	66.41395	0.3843352	0.4332503
2022	5.231144	26.97329	70.83746	70.83746	0.3355233	0.4104533
A	0,8		0,8		0,8	
β*	0,2		0,2		0,2	
Φ	-	0,9	-	0,9	-	0,9

Source: compiled and calculated by the authors based on [23]

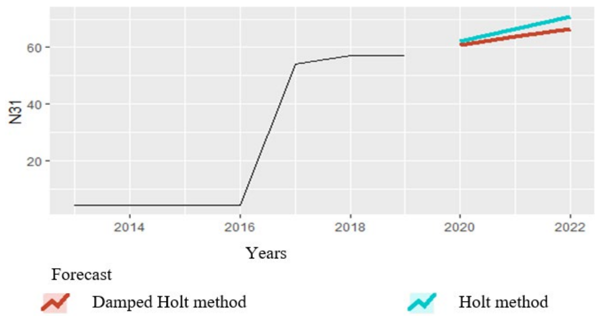
In 3 years, the projected value for the share of renewable energy consumption will be 5.143742, for the volume of gross value added of industry – 26.03699, for the global competitiveness index – 66.47696, for the development of technology and the knowledge economy – 38.83011 (Fig. 2).





The share of renewable energy consumption

The volume of gross value added of industry



The Global Competitiveness Index

Figure 2. Forecast models of industrial and technological development in terms of the indicators with a medium correlation in relation to the level of ecological and economic security for the period up to 2022.

Consequently, failure to solve the problems of previous years and the absence of effective reforms in environmental policy of industrial and technological development of the national economy pose a number of threats and risks to ensuring the level of ecological and economic security. The correlation analysis of the relationship existing between the indicators of industrial and technological development and the identification of the indicators, which have a strong and medium correlation with the level of ecological and economic security made it possible to recommend that the Ministry of Finance should expand the system of indicators and include the share of renewable energy consumption (energy security) and the global competitiveness index (macroeconomic security) in the system of assessing the level of economic security.

5. Conclusions

As a result of the evaluation, the ecosystem of Ukraine greening degree equals 0.39, what is an insufficient value according to the Harrington desirability scale, as it shows a low level of the modernization, a high level of the environmental capacity, high rates of non-renewable resources usage, a high footprint, a low level of environmental and resource payments, low labor cost and investment scope. To sum up, the fuzzy inference concerning the ecosystem greening based on the generalization of relevant parameters was validated, including the modernization degree, its environmental capacity, non-renewable resources consumption, the share of environmental investments, costs and environmental taxes in total tax revenue, footprint, and environmental friendliness of technology, manufacturing, and products. The proposed model features flexibility of a parameter set and overall structure allowing to use it for greening evaluation at all levels of eco processes. The greening parameters range is a basic one and may be expanded.

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