Assessment of ecological and economic competitiveness of regions using factor analysis

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Abstract. The article examines the assessment of ecological and economic competitiveness of regions using factor analysis. Ecological and economic competitiveness of the territory is formed from groups of components, some of which will determine its basic potential, others - the potential of possible development trajectories. The ratio of these components is different for each region and in each period of time when competitiveness is determined. Ecological and economic competitiveness of the region is determined by the ratio of several areas that interact and interdependent: social, economic, environmental. It is proposed to introduce the amount of atmospheric rent into the indicators of assessing the competitiveness of regions. Atmospheric rent is a fiscal lever of influence and a stimulus for the formation of ecological and economic competitiveness of the region. The factor analysis confirmed that the value of atmospheric rent is a significant indicator that belongs to the first, most important group of indicators, and therefore should be taken into account when conducting environmental and economic assessment. To study the ecological and economic competitiveness, there were built two models and compared by the results modeling. The most accurate model turned out to be additive, which is explained by a more balanced consideration of the load of indicators and the share of explained variation of data by each of the factors. The assessment of ecological and economic competitiveness was carried out on the example of regions of Ukraine and the ranks of these regions were determined.

1. Introduction
The current stage of development of the regional economy both in the world and in Ukraine requires active research by scientists. This is primarily due to increased interregional, national and global competition. Recently, the vector of development of economic systems is focused on the environmental component. This contributes to the formation of a new type of regional competitiveness. The importance of the environmental component of competitiveness can be proven by the results of real environmental disasters, when the importance of all other major and related subsystems was eliminated. Ecological and economic competitiveness of regions is a consequence of sustainable development of the world economic system. Therefore, there is an urgent need to increase the economic and social efficiency of market transformation, taking into account changes in the level of development of innovation, production and economic potential of the regions and compliance with modern environmental and economic challenges. Thus, increasing the ecological and economic competitiveness of regions is of renewed importance, related to adjusting the priorities of regional economy management, supporting small and medium-sized businesses due to decentralization of the economy, and forming and developing
a new market architecture that is informational and ecologically economic. It is important to recognize and take into account, along with the interests of business, environmental and economic interests of the population of the regions.

Ecological and economic directions of regional development are formed and concretized at the state level, substantiated in the legal framework, instructional documents, which regulate the purpose, objectives, principles and sequence of directions of greening economic processes and creating a system of environmental security. Thus, the Resolution of the International Environmental Forum “Environment for Ukraine” contains proposals for a policy of balanced environmental and economic development, which provides for strengthening the role of regions in its development and implementation [1]. Ensuring the environmental component of economic development is different in each state and corresponds to the strategy and scenarios of its development, which depends on the social, economic, demographic, environmental characteristics of development.

The formation of a new economic augmented reality in the socio-economic life at different levels of economic aggregation has an impact on the competitiveness of the regions, which accelerates the digitalization of the Ukrainian economy. According to Kraus, Kraus and Andrusiak [2], the transformation is carried out with the help of digital technologies, based on the introduction of innovative changes, such as BlockChain, FinTech, front office, back office, Middle office, omni-business. Due to the ever-growing interest of researchers in the sustainability of the regional economy, Martin and Sunley [3] reveal issues of regional economic sustainability. According to the study, Martinez and Poveda [ΩΩimmediateinez2022] provide an assessment of the impact of environmental indicators on competitiveness. The authors use a stochastic approach, various environmental indicators and the Global Competitiveness Index of the World Economic Forum. The results of this study are of practical importance in the development of tools, where the main elements of sustainability will be environmental performance and competitiveness. Doyle and Perez-Alaniz [5] propose to adjust the global competitiveness index to sustainability. This approach will expand the possibilities of measuring international competitiveness. The updated indicator can be used to analyze the time series and identify the relationships between indicators (economic, social and environmental) and sustainable competitiveness. The book of Huggins et al. [6] highlights the importance of the concept of competitiveness and the growing role of the region as a key spatial unit. The authors study the results of the World Index of Regional Competitiveness. This illustrates the changes in the competitiveness of regions around the world. Rizzi, Graziano and Dallara [7, 8] analyze the complex concept of sustainable competitiveness. The authors emphasize the benefits of balancing economic, social and environmental factors. Karman, Miszczuk and Bronisz [9] consider the competitiveness of regions in the context of climate change using a comparative and logical analysis of the concept of regional competitiveness and heuristic conceptual methods. Dziembala [10] notes that the key issue today is to increase the competitiveness of the regions, emphasizes the prospect of sustainability. The article proposes reformatting the composition of factors and identifying priority, namely social and environmental factors. According to the results of the grant project, Kourilova et al. had the opportunity to assess the regional competitiveness of EU regions using the methodology of the Regional Competitiveness Index [11]. The authors have identified universal and specific factors of competitiveness, and the achievement of long-term sustainable competitiveness is possible under a combination of different factors. The method of analysis of the effect of separation is proposed by Anikina and Anikin [12]. The article presents the results of calculations of the level of “environmental and economic risk” of the regions, which is an indicator of competitiveness. Kharlamova and Vertelieva [13] use cluster analysis to study national competitiveness and identify specific structures. Möbius and Althammer [14] offer a new consolidated index of sustainable competitiveness for the studied regions in 28 European countries. The authors
combine factor analysis with modeling of structural equations. This allowed us to obtain a statistically reliable index, which can be especially useful given a small sample of empirical data. The proposed index reveals the possibility of long-term sustainable competitiveness under favorable environmental, social and economic conditions.

The article proposes models of ecological and economic competitiveness, with the help of which the actual ecological and economic competitiveness of regions is assessed and their rating is obtained. Factor analysis was used to determine the most important indicators and their weight. It is proposed to introduce atmospheric rent into the indicators.

2. Materials and methods

Ecological and economic competitiveness of the territory is formed from groups of components, some of which will determine its basic potential, others the potential of possible development trajectories. The ratio of these components is different for each region and in each period of time when competitiveness is determined. We propose to identify the following groups of components of environmental and economic competitiveness of the region:

- Group I – geographical features of the region (availability of natural resources, climatic features, relief);
- Group II – assimilation potential (ability to compensate for the impact of the economic system on the environment);
- Group III – capacity of the ecological system (consumption by the economic system of the region of primary natural resources without changing the quality of the ecological system);
- Group IV – technological ability of the economic system to create and consume environmental alternatives, analogues of natural resources, secondary raw materials;
- Group V – economic incentives for investment in environmental innovation.

The environmental component has an important and special impact on certain areas of economic activity. Developed industries need more resources, attract investments that help increase production, improve product quality, accelerate its implementation, and so on. Due to traditions, the presence of similar positive experience in previous investment processes, similar successful examples of investment, fast payback periods, etc. these industries “win the competition” for resources in many regions simultaneously. At the same time, environmental factors that have a decisive influence on the competitiveness of the region’s economy are also duplicated in different areas. These features can be used in the study of environmental and economic competitiveness as a relatively stable component of the system.

Ecological and economic competitiveness of the region is determined by the ratio of several areas that interact and interdependent: social, economic, environmental.

We propose to introduce the indicator of atmospheric rent in the indicators of the ecological group. For the region, atmospheric rent is the price it has to pay to the state (an institution defined by law) for the use of atmospheric air for the production of annual GRP. The justification for the use of atmospheric rent for the regions is the statement:

(i) atmospheric rent of the region, as well as the state, is a stable indicator that is adjusted to the environmental and economic multiplier of the region. The multiplier involves changing the efficiency of production (introduction of environmental technologies), operation of environmental products and their disposal for the calendar year;

(ii) the amount of rent payment in the region is directly proportional to the social component and the cost of recreational activities. The social component, firstly, has a global vector, ie the expenditures of the region’s population on health care, preventive measures related to polluted air, morbidity, etc. are focused on world averages; secondly, it reflects regional specifics and social costs overdue (for example, related to the disposal of environmental products and taking into account their service life);
(iii) atmospheric rent of the region is the same constant indicator as the atmospheric rent of the state, which is determined by the share of participation of each region in air pollution.

The indicator of atmospheric rent of the region is calculated by the formula:

$$AR_n = CS_n - \left( C_{rrn} + \frac{E_{emn}}{EP_n} \right),$$

where $AR_n$ – atmospheric rent of the $n$-th region; $CS_n$ – social costs, which are the cost of the population for material objects in the region (prevention and prevention of degradation), the cost of the population to restore the recreational value of the region (reservoirs, forests, parks, etc.); $EP_n$ – emission of pollutants of the $n$-th region; $Ef_{emn}$ – the effectiveness of environmental measures in the $n$-th region.

Factor analysis combines methods for estimating the dimension of a set of variables by studying the structure of correlation or covariance matrices. Factor analysis assumes that the correlations between a large numbers of variables under study are determined by the existence of variables that were not included in the observation and which are smaller in number.

Let $X_1, \ldots, X_n$ to be the results of observations. Linear model:

$$X_i = \sum_{j=1}^{k} a_{ij} f_j + b_i U_i + \epsilon_i, i = 1, \ldots, n,$$

where random variables $f_i$ - general factors, random variables $U_i$ – specific factors that do not correlate with $f_i, \epsilon_i$ – random deviations, $a_{ij}$ – factor loads (loads of the $i$-th variable on the $j$-th factor), which are the general models of factor analysis. The values of $a_{ij}, b_j, \sigma^2_i$ – are unknown parameters to be estimated. Equation (2) includes a hypothesis about the covariance and variance of $x_i$, which can be tested [15].

Under the condition of a problem with one factor ($k=1$), it is sufficient to calculate the correlation between variables to unambiguously determine the load. When $k > 1$, it is impossible to unambiguously determine neither the factors nor the load, because the factors can be replaced by any orthogonal transformation with the corresponding load transformation. This quality is used to transform or rotate factors. Rotations are selected in such a way that the variables have the maximum possible load on one factor and zero or almost zero load on other factors.

Practical implementation of the factor model allows to adequately calculate the covariance structure between a relatively large numbers of observed variables due to fewer simple factors, which simplifies data analysis.

Assessment of the degree of applicability of factor analysis to a given sample can be performed using the criterion of adequacy of the Kaiser-Meyer-Olkin sample:

- $\geq 0.9$ - unconditional adequacy;
- $[0.8; 0.9)$ - high adequacy;
- $[0.7; 0.8)$ - acceptable adequacy;
- $[0.6; 0.7)$ - satisfactory adequacy;
- $[0.5; 0.6)$ - low adequacy;
- $< 0.5$ - factor analysis cannot be applied to the sample.

It is logical to use the following sequence of actions for factor analysis [15,16]:

1) calculation of the matrix of cross-correlations of indicators;
2) determining the feasibility of factor analysis using the Kaiser-Meyer-Olkin test;
3) determining the number of factors through the analysis of the eigenvalues of the matrix of cross-correlations;
4) factorization of the cross-correlation matrix;
5) rotation of the matrix of factors;
6) determination of the factor structure;
7) calculation of factor coefficients;
8) calculation of the index of ecological and economic competitiveness on the basis of calculated values (the last action is formulated for a specific task).

3. Research findings
The following initial facts were selected to study the ecological and economic competitiveness of the regions, taking into account the groups of indicators and coefficients that reflect the ecological, economic competitiveness, social (human factor) and the introduction of atmospheric rent:

\[ x_1 \] – gross regional product (at actual prices), UAH million for 1 person;
\[ x_2 \] – consumer price indices (December to December of the previous year), interest;
\[ x_3 \] – the number of business entities, including financial institutions per 10,000 population;
\[ x_4 \] – number of sole proprietors per 10,000 population;
\[ x_5 \] – volume of sold products, UAH million per 10,000 population;
\[ x_6 \] – retail trade turnover, UAH million per 10,000 population;
\[ x_7 \] – commissioning of housing, thousand m\(^2\) of total area per 10,000 population;
\[ x_8 \] – freight turnover of motor transport, million tkm per 10,000 population;
\[ x_9 \] – passenger turnover of all types of transport, million per 10,000 population;
\[ x_{10} \] – density of paved public roads, km per 1000 km\(^2\) of territory per 10,000 population;
\[ x_{11} \] – volume of sold services in the field of telecommunications and postal services (in actual prices including VAT), UAH million per 10,000 population;
\[ x_{12} \] – mobile subscribers, thousand subscribers per 10,000 population;
\[ x_{13} \] – Internet subscribers, thousand per 10,000 population;
\[ x_{14} \] – life expectancy, years;
\[ x_{15} \] – employed population aged 15-70 years, thousand people per 10,000 population;
\[ x_{16} \] – the number of students, students of vocational schools per 10,000 population;
\[ x_{17} \] – number of students, students of higher education institutions per 10,000 population;
\[ x_{18} \] – household income, UAH million;
\[ x_{19} \] – the value of total expenditures of households on average per month per household, UAH;
\[ x_{20} \] – number of doctors of all specialties per 1 person;
\[ x_{21} \] – housing stock, thousand m\(^2\) of total area per 1 person;
\[ x_{22} \] – the number of detected crimes (cases) per 10,000 population;
\[ x_{23} \] – number of tourists served by tour operators and travel agents (persons) per 1 person;
\[ x_{24} \] – volume of discharge of polluted return waters into surface water bodies, million m\(^3\) per 1 person;
\[ x_{25} \] – volume of waste generation per km\(^2\) tons;
\[ x_{26} \] – volume of emissions of pollutants into the atmosphere from stationary sources of pollution, thousand tons;
\[ x_{27} \] – volume of waste generation per person, kg;
\[ x_{28} \] – total amount of waste accumulated during operation in waste disposal sites, thousand tons per 1 person;
\[ x_{29} \] – the amount of capital investments in environmental protection, UAH million;
\[ x_{30} \] – the amount of current expenditures on environmental protection, UAH million;
\[ x_{31} \] – the amount of atmospheric rent, UAH million.
Among the selected indicators, the indicators $x_1 - x_{13}$ belong to the economic group of indicators, the indicators $x_{14} - x_{23}$ – to the social group of indicators, the indicators $x_{24} - x_{30}$ – to the environmental group. The atmospheric rent indicator introduced in this study $x_{31}$ will be referred to the ecological group of indicators.

In order to ensure the accuracy of the analysis, the initial data for each indicator were pre-normalized by the formula:

$$y_{norm} = \frac{y - M(y)}{\sigma(y)},$$

where $M(y)$ – the mathematical expectation determined for the current time series; $\sigma(y)$ – standard deviation.

During the following calculation of the assessment of environmental and economic competitiveness, the initial data were reduced to the interval $[0;1]$ using the formula:

$$\hat{x} = \frac{x - \min(x)}{\max(x) - \min(x)}$$

which is explained by the requirements of the resulting calculation models to the original data, in particular, the requirement of non-integrity, while the use of formula (3) leads to fluctuations in values around 0.

There were analyzed 465 values in total. Given the symmetry of the cross-correlation matrix and without taking into account the units on the main diagonal of the matrix, it had 289 positive elements out of 465 elements in total, which is satisfactory for the analysis.

The value of the Kaiser-Meier-Olkin test is 0.89, which indicates the high adequacy of the sample to factor analysis.

The number of factors was determined by the number of eigenvalues of the matrix of cross-correlations greater than 1, based on this it was concluded that there are 7 factors. Table 1 shows the first ten eigenvalues, sorted in descending order, together with the percentage of data variation due to the relevant factor. As can be seen from table 1, together the first 7 factors explain 86.5% of variations in all data, which is a high indicator.

| № | Eigenvalue | The explanatory percentage of variation | Cumulative explanatory percentage of variation |
|---|------------|-----------------------------------------|-----------------------------------------------|
| 1 | 10.507746  | 33.895955                               | 33.895955                                     |
| 2 | 4.783858   | 15.431802                               | 49.327757                                     |
| 3 | 3.771401   | 12.165810                               | 61.493567                                     |
| 4 | 2.842798   | 9.170316                                 | 70.663883                                     |
| 5 | 2.215177   | 7.145732                                 | 77.809614                                     |
| 6 | 1.482508   | 4.782285                                 | 82.591900                                     |
| 7 | 1.212210   | 3.910354                                 | 86.502254                                     |
| 8 | 0.814161   | 2.626325                                 | 89.128579                                     |
| 9 | 0.656179   | 2.116708                                 | 91.245287                                     |
| 10| 0.597984   | 1.928982                                 | 93.174268                                     |

After factorization of the cross-correlation matrix and rotation of the factorized matrix, only indicators with a load value greater than 0.70 were selected from the resulting matrix. The result of the calculations is presented in table 2.
Table 2. Classification of the studied indicators by factors.

| Indicators | Factors |
|------------|---------|
|            | 1       | 2   | 3   | 4   | 5   | 6   | 7   |
| 1          |         |     |     |     |     |     | 0.84|
| 2          |         |     |     |     |     |     |     |
| 3          |         |     |     |     |     |     |     |
| 4          |         |     |     |     |     |     |     |
| 5          |         | 0.72|     |     |     |     |     |
| 6          |         |     |     |     |     |     |     |
| 7          |         |     | 0.89|     |     |     | 0.83|
| 8          |         | 0.75|     | 0.75|     |     |     |
| 9          |         |     |     |     |     |     |     |
| 10         |         | 0.75|     |     |     |     |     |
| 11         |         |     |     |     |     |     |     |
| 12         |         |     |     |     |     |     |     |
| 13         |         | 0.78|     |     |     |     |     |
| 14         |         |     |     | 0.82|     |     |     |
| 15         |         |     |     |     |     |     |     |
| 16         |         |     |     |     |     |     |     |
| 17         |         | 0.73|     |     |     |     |     |
| 18         |         |     |     |     |     |     |     |
| 19         |         |     |     |     |     |     |     |
| 20         |         |     |     |     |     |     |     |
| 21         |         |     |     |     |     |     |     |
| 22         |         | 0.75|     |     | 0.72|     |     |
| 23         |         |     |     |     |     |     |     |
| 24         |         | 0.9 |     |     | 0.9 |     |     |
| 25         |         |     |     |     |     |     |     |
| 26         |         | 0.81|     |     |     |     |     |
| 27         |         |     |     |     |     |     | 0.85|
| 28         |         | 0.92|     |     |     |     |     |
| 29         |         |     |     |     |     |     | 0.83|
| 30         |         |     |     |     |     | 0.82|     |
| 31         |         |     |     |     |     |     | 0.84|

Of the seven pre-determined factors, only 6 are applicable, as for the last, seventh, factor there are no indicators with a high value of load. In total, the factors include 19 indicators, which reduces the amount of data processed in the process of assessing environmental and economic competitiveness. Among the selected indicators, 7 belong to the economic group of indicators, 4 - to the group of social indicators, the remaining 8 - to the group of environmental indicators (ie all indicators of this group). The first factor, which covers 9 indicators at once, deserves attention:

1 from the group of economic indicators (volume of sold products);
2 from the group of social indicators (income, crime rate);
6 from the group of environmental indicators.

Given that the first factor explains almost 34% of the variation in the data, the indicators of this share have the most significant impact on the system as a whole, and therefore will be the most important indicators for assessing environmental and economic competitiveness. Note that the value of atmospheric rent belongs to the indicators of factor 1.
The conducted factor analysis allowed to identify the most important indicators and determine the weight of individual groups of indicators, which was taken into account for the development of models for refined assessment of environmental and economic competitiveness.

To assess the ecological and economic competitiveness, there were used two models, which differently take into account the obtained values of the load of factors and the percentage of variations explained by factors.

In the first model, calculations are performed according to the formulas:

\[
F_i = \sqrt{N_i \prod_{k=1}^{N_i} \hat{x}_{ik} f_{ik}},
\]

\[
I = \sqrt{N \prod_{i=1}^{N} F_i},
\]

where \(\hat{x}_{ik}\) – the value of the \(k\)-th indicator related to the corresponding factor; \(f_{ik}\) – load of the \(k\)-th indicator in the \(i\)-th factor; \(N_i\) – the number of indicators in the \(i\)-th factor; \(F_i\) – the value of the \(i\)-th factor; \(N\) – number of factors; \(I\) – the value of assessing environmental and economic competitiveness.

In the second model, calculations are performed according to the formulas:

\[
F_i = \sum_{k=1}^{N_i} f_{ik} \cdot \hat{x}_{ik},
\]

\[
I = \sum_{k=1}^{N} p_k \cdot F_k,
\]

where \(\hat{x}_{ik}\) – the value of the \(k\)-th indicator related to the corresponding factor; \(f_{ik}\) – load of the \(k\)-th indicator in the \(i\)-th factor; \(N_i\) – the number of indicators in the \(i\)-th factor; \(F_i\) – the value of the \(i\)-th factor; \(p_k\) – the proportion of the explained variation by the factor \(k\); \(N\) – number of factors; \(I\) – the value of assessing environmental and economic competitiveness.

Model (7)-(8) is additive, which also takes into account the load of indicators and the share of data variation explained by factors. By its nature, the second model is more like an expert assessment of environmental and economic competitiveness.

Table 3 summarizes the values of environmental and economic competitiveness estimates obtained using the described models and the corresponding ranks of the regions.

Analysis of assessments of ecological and economic competitiveness of regions allows us to conclude that, first, the result is stable, because for 12 regions out of 22 ranks obtained by different models differ by no more than 3 points. Secondly, the comparison of the results of the built models with the average value of the competitiveness index shows greater similarity of the results of model (7)-(8) and is explained by the higher accuracy of the model by choosing the indicators that carry the greatest load.

4. Conclusion

According to the results of the study using factor analysis, 7 groups of indicators were identified that most significantly affect the assessment of environmental and economic competitiveness and are the basis for its assessment. The identified indicators can be decisive for the development of regional and state development strategy (environmental and economic component).

The authors propose an introduction to the indicators of assessing the competitiveness of the regions of the value of atmospheric rent. Atmospheric rent is a fiscal lever of influence and a
Table 3. Assessment of ecological and economic competitiveness of regions.

| Region           | Model (5)-(6) Index value | Rank | Model (7)-(8) Index value | Rank |
|------------------|---------------------------|------|---------------------------|------|
| Vinnytska        | 0.2715                    | 8    | 0.7973                    | 9    |
| Volynska         | 0.2578                    | 9    | 0.6220                    | 14   |
| Dnipropetrovsk   | 0.3738                    | 1    | 2.6053                    | 1    |
| Zhytomyrska      | 0.2165                    | 18   | 0.5507                    | 17   |
| Zakarpatska      | 0.2395                    | 11   | 0.4451                    | 21   |
| Zaporizka        | 0.2155                    | 19   | 1.3613                    | 2    |
| Ivano-Frankivsk  | 0.2968                    | 4    | 0.7745                    | 10   |
| Kyivska          | 0.3503                    | 3    | 1.2052                    | 3    |
| Kirovohradsk     | 0.2232                    | 15   | 0.6116                    | 15   |
| Lvivska          | 0.2728                    | 7    | 1.1348                    | 4    |
| Mykolaiivska     | 0.1953                    | 21   | 0.8300                    | 8    |
| Odeska           | 0.3702                    | 2    | 1.0975                    | 5    |
| Poltavskv        | 0.2538                    | 10   | 0.9754                    | 7    |
| Rivnenksa        | 0.2780                    | 5    | 0.5350                    | 18   |
| Sumskv           | 0.2169                    | 17   | 0.7035                    | 11   |
| Ternopilska      | 0.2095                    | 20   | 0.5101                    | 19   |
| Kharkivskv       | 0.2393                    | 12   | 0.9816                    | 6    |
| Khersonksk       | 0.1688                    | 22   | 0.4315                    | 22   |
| Khmelnytska      | 0.2777                    | 6    | 0.5929                    | 16   |
| Cherkaska        | 0.2282                    | 13   | 0.6965                    | 12   |
| Chernivtska      | 0.2248                    | 14   | 0.4753                    | 20   |
| Chernihivska     | 0.2198                    | 16   | 0.6313                    | 13   |

stimulus for the formation of ecological and economic competitiveness of the region. The factor analysis confirmed that the value of atmospheric rent is a significant indicator that belongs to the first, most important group of indicators, and therefore should be taken into account when conducting environmental and economic assessment.

To study the ecological and economic competitiveness, two models were built and the results of modeling were compared. The most accurate model turned out to be additive, which is explained by a more balanced consideration of the load of indicators and the share of explained variation of data by each of the factors. The assessment of ecological and economic competitiveness was carried out on the example of regions of Ukraine and the ranks of these regions were determined.

The proposed methodology can be used to assess the environmental and economic competitiveness of regions for any country in the world.

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