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A Methodical Approach to Assessing the Level of Economic and Ecological Potential of the Agricultural Sector of the Region Based on Fuzzy Logic

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ABSTRACT
The results of the study made it possible to identify the most influential parameters and group them by four key components of the economic and environmental potential of the agricultural sector of the region. The proposed methodical approach allows taking into account not only quantitative indicators, but also qualitative ones, which can be evaluated using linguistic terms. This contributes to obtaining reliable information for the timely adoption of appropriate management decisions on the adaptability of the economic and environmental potential of the agricultural sector of the region to adverse internal and external factors.

Given the current difficult conditions in the country, ensuring sustainable development of regions requires the search for effective mechanisms to increase their functionality. The agro-industrial complex continues to be one of the most important and promising sectors of the economy.

Thus, the process of formation and implementation of the main strategic directions of regional development requires the development of a methodological approach to assess the level of economic and environmental potential of the agro-industrial complex, which would take into account various indicators that affect it, and would contribute to a quick and adequate response to external and internal changes.

Keywords: economic potential, ecological potential, methodical approach, theory of fuzzy logic, set, agro-industrial complex of the region, evaluation.

JEL Classification: C61, O13, O18, R49

INTRODUCTION

Since February 24, 2022, due to the Russian military invasion, Ukraine's industries and infrastructure on the whole have undergone drastic negative changes. In addition to human lives and health, the country is losing everything that it has built, created, and produced for many years. However, we are a strong nation that "does not lose heart"! Ukraine has a powerful resource potential, hardworking population that able to rebuild and contribute to the effective economic development of the country.

Agricultural production remains one of the main sources of stable functioning of regions. Favorable geographical location, moderate climate, fertile soil as well as many other factors contribute to the effective development of this sector of the economy. However, one should not forget about the eternal problem of limited resources and our growing needs. For more than a dozen years scientists around the world have been trying to inform the society about the possible onset of a global environmental crisis.

Manufacturers are so obsessed with the desire to achieve maximum financial results that they forget about the negative impact on the environment. It is clear that the transition to a new economic and ecological development requires additional financial costs from business entities, but it will make it possible to solve the main tasks of saturating the market with high-quality environmentally friendly products, reduce the negative impact on nature, promote more efficient use of natural resources, and expand markets sales due to the growth of competitive advantages of agricultural products [22].

That is why it is important to assess the economic and ecological potential of the agricultural sector of the region, which will allow identifying problem areas in the functioning of the agrarian sector and form the main directions for improving its efficiency.

LITERATURE REVIEW

Regarding methodical approaches and indicators for assessing the economic and ecological potential of the agricultural sector of the region, suffice it to mention that a significant number of scientists partially raised this issue in their works. However, to date, there is still no consensus on the methods and means to solve this problem.

Each author proposes his vision of the main parameters of the assessment of the economic and environmental component. Andrusiak N.O. [1;2] emphasizes the importance of indicators for assessing the ecological and economic competitiveness of the country and the region. Tackling this issue, the author places more emphasis on the economic components of competitiveness. In addition, the scientist's proposed classification of possible methods for assessing the competitiveness of regions, which were grouped by a number of general scientific classification features, deserves attention.

A group of scientists [3], who single out such components as natural resources, labor and production potentials, propose well-grounded argumentation of the integral indicators of the economic potential of regions.

According to Ladonko L.S. [4], it is advisable to group the effective indicators of the economic potential of the region in the following areas: strategizing regional development, operational management of the region, innovation-investment, social-economic, recreational-tourism development of the region, creation of competitive advantages through the creation of a positive image of the region. This approach involves taking into account a fairly significant number of evaluation parameters, including qualitative ones, for which, unfortunately, there is no evaluation mechanism. For example, an indicator of the local business climate or the quality and structure of medical and educational institutions.

Having analyzed the existing approaches, it can be concluded that each author quite subjectively assesses the economic and ecological potential of the region, giving preference to one or another of its components. However, despite the large number of scientific achievements in this area of research, the issue of a methodical approach to assessing the economic and ecological potential of the agricultural sector of the region, which is the goal of the study, remains unresolved [17;21].

OBJECTIVES

The purpose of the article is to develop and substantiate a mathematical model for assessing the level of economic and ecological potential of the agricultural sector of the region based on fuzzy logic. To achieve the goal of the research, it is necessary to: analyze the existing approaches to the assessment of the economic and ecological components of the development of the agricultural sector of the region; to select and justify a set of basic indicators, which can be used to assess the level of functioning of these components; using the mathematical apparatus of fuzzy logic to develop a comprehensive approach to assessing the level of economic and ecological potential of the agricultural sector of the region.

METHODS

The methodological and theoretical foundations of the research include the key concepts of modern economic theory, as well as publications of domestic and international experts related to the assessment of the economic and environmental potential of the agricultural sector in the regions. The following methods were used in the study: Analysis and synthesis for the study of the main principles of economic and ecological potential. An economic-statistical method for the analysis of variations in indicators of the economic and ecological potential of the agricultural sector in the regions. An expert method for collecting expert opinions on the assessment of the potential of the agricultural sector. A graphical method for determining membership functions. Economic and mathematical modeling to create a model for assessing the level of economic and ecological potential of the agrarian sector. Insufficient efficiency and reliability of existing systems for assessing the level of economic and ecological potential of the agricultural sector makes it difficult to identify and promptly eliminate possible problems. However, the development of a new evaluation system will allow potential investors to objectively evaluate the development of the agricultural sector in the region, which may contribute to attracting additional financial resources. We propose to create a new methodical approach for assessing the level of the economic and ecological potential of the agricultural sector of the region, which includes a mathematical model using the theory of fuzzy sets and linguistic variables. This allows taking into account both quantitative and qualitative indicators given by vague statements. The choice of using fuzzy logic to build a mathematical model is due to the lack of complete statistical data and the need to reconcile conflicting criteria when formulating recommendations. The theory of fuzzy logic makes it possible to take into account the variations of input indicators, their evaluation using terms, and automated modeling that allows you to track changes in input parameters taking into account the opinions of experts.

DESCRIPTION OF THE PROJECT

It is important to note that fuzzy logic theory (or fuzzy technology, or the theory of fuzzy sets) encompasses "a collection of theoretical principles, methods, algorithms, procedures, and software tools that utilize fuzzy reasoning and expert assessments on specific issues" [2;3]. The algorithm for implementing models based on fuzzy logic theory, along with its principal theoretical and practical aspects, is extensively discussed in various studies [2;21].

The process of evaluating the economic and ecological potential of the agricultural sector in a region involves the following sequential steps:

1. Determine and justify the key parameters for assessing the economic and ecological potential of the region's agricultural sector and establish their change limits.
2. Construct a tree illustrating the relationships between the selected indicators.
3. Create membership functions for fuzzy estimates, formalizing each term used for evaluating the chosen parameters with fuzzy sets.
4. Develop a knowledge base using expert opinions on the relationships between fuzzy terms for input and output linguistic variables.
5. Generate fuzzy logic equations based on the established knowledge base.
6. Convert vague information into a precise form.

Upon reviewing various approaches to assessing the economic and ecological potential of the agricultural sector in regions, a set of fundamental parameters was selected and validated through expert evaluation. This allowed for a comprehensive assessment of the region's potential. The proposed indicators should be categorized into four primary changes: the economic potential of the agricultural sector; the ecological potential of the agricultural sector; regional characteristics affecting the economic and ecological potential; and the impact of external factors on the economic and ecological potential of the agricultural sector.

THE RESULTS

Based on the main provisions of the theory of fuzzy logic, the task of assessing the level of economic and ecological potential of the agricultural sector of the region will look like this:

$$Y = \{X_1, X_2, X_3, X_4\} \rightarrow d \in D = \{d_1, d_2, d_3, d_4, d_5\}, \quad (1)$$

where Y is a set of indicators of the level of economic and ecological potential of the agricultural sector of the region;

D is a set of possible levels of economic and ecological potential of the agricultural sector of the region.

Therefore, the set of X indicators for evaluating the economic and ecological potential of the agricultural sector of the region will consist of the following groups of indicators:

X_1 – the level of economic potential of the agricultural sector of the region;

X_2 – the level of ecological potential of the agricultural sector of the region;

X_3 – the level of regional features of the economic and ecological potential of the agricultural sector of the region;

X_4 – the level of influence of external factors on the economic and ecological potential of the agricultural sector of the region.

That is, a comprehensive assessment of the level of the economic and ecological potential of the agricultural sector of a certain region will be based on the calculated values of the above groups of indicators and will have the following form:

$$Y = f_Y\left(X_1, X_2, X_3, X_4\right) \quad (2)$$

As mentioned above, each group represents a set of indicators included in it. Thus, the level of the economic potential of the agricultural sector of the region will have the following form:

$$X_1 = f_1\left(X_{11}, X_{12}, X_{13}, X_{14}, X_{15}, X_{16}, X_{17}\right), \quad (3)$$

where X_{11} is the specific weight of agricultural products in the gross regional product;

X_{12} – volume of production of agricultural products per 100 hectares of agricultural land;

X_{13} – specific weight agribusiness products in the general export structure of the region;

X_{14} – specific weight of agricultural land in the total area of the region;

X_{15} – labor productivity of agricultural sector workers;

X_{16} – the share of innovatively active agribusiness enterprises in the total number of agribusiness enterprises in the region;

X_{17} – the share of innovative products in the total volume of sales of agricultural products of the region;

X_{18} – profitability of agricultural production;

X_{19} – seasonality of production;

X_{110} – the level of provision of material and technical means;

X_{111} – level of knowledge and professional skills;

X_{112} – the share of investments in the agricultural industry from the total volume of investments in the economy of the region;

X_{113} – the level of information support for the agricultural sector of the region;

X_{114} – coefficient of utilization of production capacity by agro-industrial complex enterprises;

X_{115} – the degree of wear and tear of the main means of production by agro-industrial complex enterprises;

X_{116} - the area of agricultural land in the region.

The level of ecological potential of the agricultural sector of the region includes the following parameters that affect it:

$$X_2 = f_2\left(X_{21}, X_{22}, X_{23}, X_{24}, X_{25}, X_{26}, X_{27}, X_{28}, X_{29}, X_{210} X_{211}, X_{212}\right), \quad (4)$$

where X_{21} is the share of pollutant emissions from an agricultural enterprise and its machinery among the total volume of emissions of the region;

X_{22} – level of water pollution in the region;

X_{23} – the specific weight of eco-products in the total volume of agricultural production;

X_{24} – the specific weight of the introduction of eco-technologies at the enterprises of the agricultural industry;

X_{25} – the weight of the financing of ecological production;

X_{26} – level of use of environmentally beneficial raw materials;

X_{27} – share of surface water pollution by agribusiness enterprises from total water pollution in the region;

X_{28} – the share of air emissions by agro-industrial complex enterprises from the total air pollution in the region;

X_{29} – the share of accumulated agricultural waste from the total amount of generated waste in the region;

X_{210} – specific weight of the area of agricultural land fertilized with organic fertilizers;

X_{211} is the specific weight of the area occupied by the production of organic products in the total area of agricultural plots.

The set of input parameters that characterize the level of regional features of the economic and ecological potential of the agricultural sector of the region will look like this:

$$X_3 = f_3\left(X_{31}, X_{32}, X_{33}, X_{34}, X_{35}, X_{36}, X_{37}, X_{38}, X_{39}, X_{310,} X_{311}, X_{312}\right) \qquad (5)$$

where X_{31} is the level of depletion of natural resources;

X_{32} – the level of environmental awareness of the population;

X_{33} – the share of costs for environmental protection in the region;

X_{34} – industry relations of the enterprise;

X_{35} – natural conditions of the region;

X_{36} – soil fertility;

X_{37} – unemployment rate in the region;

X_{38} – climate of the region;

X_{39} – employment level of the region;

X_{310} – water supply of the region.

The level of influence of external factors on economic and environmental potential of the agricultural sector of the region are characterized by the following indicators:

$$X_4 = f_4\left(X_{41}, X_{42}, X_{43}, X_{34}\right), \qquad (6)$$

where X_{41} is the level of socio-demographic development;

X_{42} – state of the labor market;

X_{43} – level of education of the population;

X_{44} – the level of institutional and legal support of the agricultural industry;

X_{45} – economic and political situation in the country;

X_{46} – purchasing power of the population;

X_{47} – demand for agricultural products

According to the next stage of building the model, it is necessary to evaluate the linguistic indicators that affect the level of economic and ecological potential of the agricultural sector of the region, using a system of qualitative terms.

The range of changes in input parameters was compiled on the basis of a thorough analysis of literary sources in this area of research and statistical data of agribusiness enterprises and regions of Ukraine. It is worth noting that for qualitative indicators, it is suggested to use a rating scale from "1" to "10" points.

The system of evaluative qualitative terms for linguistic variables is presented in the table. 1.

Table 1 Linguistic assessment of input parameters

Name of the input parameter (variable)	The range of parameter change/variation	Terms for assessing input parameters/ low (L); medium (M); high (H); very low (vL);
1	2	3
X_1 – the level of economic potential of the regions' agricultural complex		
X_{11} – specific weight of the products of the agricultural complex (AC) in the gross regional product	10…60 %	(L); (M); (H)
X_{12} – the volume of production of an	500-4000	(L); (M); (H)

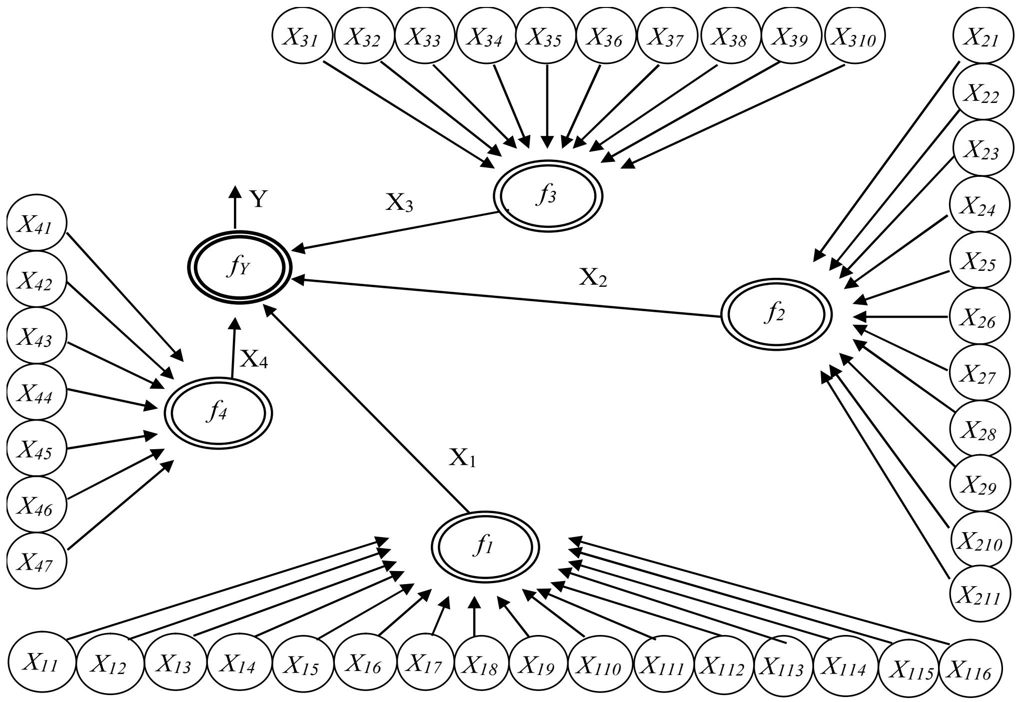
agricultural enterprise per 100 hectares of farmland		
X_{13} – specific weight of the AC produce in the region's general export structure	30…90 %	(L); (M); (H)
X_{14} – share of arable land in the region's general area	30…90 %	(L); (M); (H)
X_{15} labour productivity of the whole AC	100…1000	(L); (M); (H)
X_{16} – share of innovative enterprises in the AC out of the general number of region's agricultural enterprises	0…50 %	(L); (M); (H)
X_{17} – specific weight of innovative products in the general volume of the sold	0…50 %	(L); (M); (H)
X_{18} – production profitability of the AC	0…50 %	(L); (M); (H)
X_{19} – seasonal production/output index	70 – 120 %	(L); (M); (H)
X_{110} –maintenance supply level	1…10	(L); (M); (H)
X_{111} – proficiency level	1…10	(L); (M); (H)
X_{112} – shareof investments in AC among the general investments into the region's economy	0…50 %	(L); (M); (H)
X_{113} – region's AC's informational support level	1…10	(L); (M); (H)
X_{114} – the rate of production capacity use of AC enterprises	0,2…1	(vL); (L); (M); (H)
X_{115} – wear on the main equipment at the AC enterprises	30 – 80 %	(L); (M); (H)
X_{116} – arable land area of the region	100 – 2500	(L); (M); (H)
X_2 – ecological potential level of the AC		
X_{21} – share of emissions from the AC fixed sources of pollution in the general volume of region's emissions	0…50 %	low (L); medium (M); high (H)
X_{22} – water pollution level in the region	1…10	low (L); medium (M); high (H)
X_{23} – share of ecological products in the general volume of the AC output	0…50 %	low (L); medium (M); high (H)

Continuation of table 1

1	2	3
X_{24} – specific weight of introducing eco-friendly technologies	0…50 %	low (L); medium (M); high (H)
X_{25} – specific weight of financing eco-friendly technologies	0…50 %	low (L); medium (M); high (H)
X_{26} – utilization of ecological raw ware	1…10 points	low (L); medium (M); high (H)
X_{27} – share of water pollution by the AC enterprises out of the general water pollution in the region	0…50 %	low (L); medium (M); high (H)
X_{28} – share of air emissions by the AC enterprises in the general air pollution in the region	0…50 %	low (L); medium (M); high (H)
X_{29} – share of accumulated agricultural waste of the general volume of region's waste	0…50 %	low (L); medium (M); high (H)
X_{210} – specific weight of the organically fertilized farm land	0…30 %	low (L); medium (M); high (H)
X_{211} – specific weight of the area used for organic plants out of the general arable area	0…30 %	low (L); medium (M); high (H)
X_3– level of regional properties of economic ecological potential of the region's AC		
X_{31} – level of natural resource depletion	1…10 points	low (L); medium (M); high (H)
X_{32} – level of environmental awareness in public	1…10 points	low (L); medium (M); high (H)
X_{33} – share of expenditures for environmental protection in the region	0…50 %	low (L); medium (M); high (H)
X_{34} – industries coordination	1…10 points	negative (N); stable (S); positive (P)
X_{35} – region's natural conditions	1…10 points	infavourable (iF); partially infavourable (piF); favourable (F)
X_{36} – soil fertility	1…10 points	low (L); medium (M); high (H)
X_{37} – unemployment level in the region	0…20 %	low (L); medium (M); high (H)
X_{38} – region's climate	1…10 points	low (L); medium (M); high (H)
X_{39} – employment level in the region	40…80 %	low (L); medium (M); high (H)
X_{310} – water supply level in the region	1…10 points	low (L); satisfactory (S); high (H)
X_4– level of external impact in the economic ecological potential of the region's AC		
X_{41} – the level of socio-demographic development	1…10 points	low (L); medium (M); high (H)
X_{42} – labour market condition	1…10 points	low (L); medium (M); high (H)
X_{43} – public education level	1…10 points	low (L); medium (M); high (H)
X_{44} – the level of institutional and legal support of the AC	1…10 points	low (L); satisfactory (S); high (H)
X_{45} – economic and political situation in the country	1…10 points	Negative (N); stable (S); positive (P)
X_{46} – public purchase capacity	1…10 points	low (L); medium (M); high (H)
X_{47} – *demand for the produce of the AC*	1…10 points	low (L); medium (M); high (H)

Source: *authors' own development*

The construction of a tree of fuzzy logical conclusion (hierarchical relationship of the selected parameters) involves a graphic representation of a set of indicators for assessing the level of economic and ecological potential of the agricultural sector of the region, given in the table, and their relationship and influence on the final result (Fig. 1). Yes, from the picture it can be seen that the evaluation is carried out in two stages: first, we evaluate the intermediate output parameters of the model using a set of indicators, and then we evaluate the final result, that is, the level of the economic and ecological potential of the agricultural sector of the region.



L	LM	M	MH	H

Fig. 1. Tree of logical conclusion of the level of economic and ecological potential of the agricultural sector of the region

Source: *authors' own development*

The next stage of evaluation is the selection of a method of constructing membership functions, which will make it possible to formalize with fuzzy sets each of the terms to evaluate linguistic parameters. The theory of fuzzy sets involves the use of various such methods. The construction of membership functions aims to phaseize fuzzy estimates of influence factors. In other words, we can say that with the help of experts, vague terms were set for the linguistic evaluation of the proposed input indicators. The fuzzy set, with the help of which the term *F* is formalized, is a set of pairs:

$$F = \frac{\mu_F(u_1)}{u_1} + \frac{\mu_F(u_2)}{u_2} + \ldots + \frac{\mu_F(u_n)}{u_n}, \qquad (7)$$

where $(u_1, u_2, \ldots, u_n) = U$ is the universal set on which the fuzzy set is defined $F \in U$;

$\mu_F(u_i)$ - degree of ownership of the element $u_i \in U$ to the fuzzy set *F* [9] .

An unknown membership function assumes a set of values $\mu_F(u_i)$ to all $i = \overline{1,n}$, to be determined. The method of solving this problem is based on the idea of distributing the degrees of membership of a universal set according to its ranks. "The rank of an element is called a number $r_F(u_i)$, which indicates the importance of this element in the formation of a property described by fuzzy expressions $\widetilde{F}$. The higher the rank of the element, the higher the degree of its belonging" [12].

Given the normalization condition ($\mu_1 + \mu_2 + \mu_n = 1$), the rule for the distribution of degrees of belonging can be presented in the form of the following ratio:

$$\frac{\mu_1}{r_1} = \frac{\mu_2}{r_2} = \ldots = \frac{\mu_n}{r_n} \tag{8}$$

The indicated degrees of affiliation $\mu_F(u_i)$ elements of the set to a fuzzy term $\widetilde{F}$ determined by the formulas:

$$\left.\begin{aligned} \mu_1 &= \left(1 + \frac{r_2}{r_1} + \frac{r_3}{r_1} + \ldots + \frac{r_n}{r_1}\right)^{-1} \\ \mu_2 &= \left(\frac{r_1}{r_2} + 1 + \frac{r_3}{r_2} + \ldots + \frac{r_n}{r_2}\right)^{-1} \\ &\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ \mu_n &= \left(\frac{r_1}{r_n} + \frac{r_2}{r_n} + \frac{r_3}{r_n} + \ldots + 1\right)^{-1} \end{aligned}\right\} \tag{9}$$

During the construction of the membership function for each pair of elements of the universal set, the expert evaluates the advantages of one element over the other with respect to the properties of the fuzzy set $\frac{r_i}{r_j} = a_{ij}$ $i, j = \overline{1, n}$. Such pairwise comparisons form a matrix:

$$A = \begin{bmatrix} 1 & \frac{r_2}{r_1} & \frac{r_3}{r_1} & \ldots & \frac{r_n}{r_1} \\ \frac{r_1}{r_2} & 1 & \frac{r_3}{r_2} & \ldots & \frac{r_n}{r_2} \\ \ldots & \ldots & \ldots & \ldots & \ldots \\ \frac{r_1}{r_n} & \frac{r_2}{r_n} & \frac{r_3}{r_n} & \ldots & 1 \end{bmatrix} \tag{10}$$

It is appropriate to note the features of this matrix, namely: it is diagonal, i.e $a_{ii} = 1$, $i = \overline{1, n}$; elements of the matrix, symmetrical about the main diagonal, are related by the ratio: $a_{ij} = 1/a_{ji}$; the matrix is transitive, that is $a_{ik} \cdot a_{kj} = a_{ij}$, since $\frac{r_i}{r_k} \cdot \frac{r_k}{r_j} = \frac{r_i}{r_j}$, you can after finding the elements of one row, determine the elements of all other rows . Since the matrix can be interpreted as a matrix of pairwise comparisons of ranks, the 9-point Saati scale is used for expert assessment of the elements of this matrix.

Since the construction of appropriateness functions of input indicators is based on expert evaluations, the input parameters of the model were evaluated by experts in this direction of research (scientists, specialists of agro-industrial complex enterprises, the Department of Agro-Industrial Complex, Vinnytsia Regional State Administration, etc. acted as experts).

According to the modeling algorithm, the appropriateness functions of the input parameters of the assessment of the level of the economic and ecological potential of the region’s agricultural sector are constructed. Thus, for the linguistic variable X_{11} - "specific weight of agricultural production in the gross regional product" the universal set is [10...60%]. For evaluation, it is proposed to use the following vague terms: H – low; C – average; B is high. In Table 2, matrices were formed for each term, where separate properties u_1 , u_2 , u_3 were found according to formula (10).

The calculated membership functions are normalized to unity by dividing them by the maximum degree of membership, resulting in the variable " specific weight of agricultural products in the gross regional product » presented in the form of fuzzy sets:

specific weight of agricultural products in GDP "low" = $\left\{\frac{1}{0};\frac{0{,}43}{0{,}75};\frac{0{,}16}{1{,}5}\right\}$

specific weight of agricultural products in GRP "average" = $\left\{\frac{0{,}50}{0};\frac{1}{0{,}75};\frac{0{,}86}{1{,}5}\right\}$

the specific weight of agricultural products in GRP is "high" = $\left\{\frac{0{,}38}{0};\frac{0{,}50}{0{,}75};\frac{1}{1{,}5}\right\}$

Table 2 Matrices of pairwise comparisons and degrees of membership for the input variable X_{11} - "specific weight of agricultural products in the gross regional product"

Evaluation terms	Matrix of pair equation	Dependency degrees
LOW	$\begin{array}{c\|c\|c\|c} & u_1 & u_2 & u_3 \\ \hline u_1 & 1 & 3/7 & 1/6 \\ u_2 & 7/3 & 1 & 4/6 \\ u_3 & 6/1 & 6/4 & 1 \end{array}$	$\mu(u_1)=\frac{1}{1+3/7+1/6}=0{,}63$ $\mu(u_2)=\frac{1}{7/3+1+4/6}=0{,}25$ $\mu(u_3)=\frac{1}{6/1+6/4+1}=0{,}12$
AVERAGE	$\begin{array}{c\|c\|c\|c} & u_1 & u_2 & u_3 \\ \hline u_1 & 1 & 8/4 & 7/2 \\ u_2 & 4/8 & 1 & 6/7 \\ u_3 & 2/7 & 7/6 & 1 \end{array}$	$\mu(u_1)=\frac{1}{1+8/4+7/2}=0{,}15$ $\mu(u_2)=\frac{1}{4/8+1+6/7}=0{,}42$ $\mu(u_3)=\frac{1}{2/7+7/6+1}=0{,}41$
HIGH	$\begin{array}{c\|c\|c\|c} & u_1 & u_2 & u_3 \\ \hline u_1 & 1 & 7/5 & 8/3 \\ u_2 & 5/7 & 1 & 8/4 \\ u_3 & 3/8 & 4/8 & 1 \end{array}$	$\mu(u_1)=\frac{1}{1+7/5+8/3}=0{,}20$ $\mu(u_2)=\frac{1}{5/7+1+8/4}=0{,}27$ $\mu(u_3)=\frac{1}{3/8+4/8+1}=0{,}53$

Source: *authors' own research*

Graphically, the membership function for the linguistic variable "specific weight of agricultural products in the gross regional product" is shown in Fig. 2

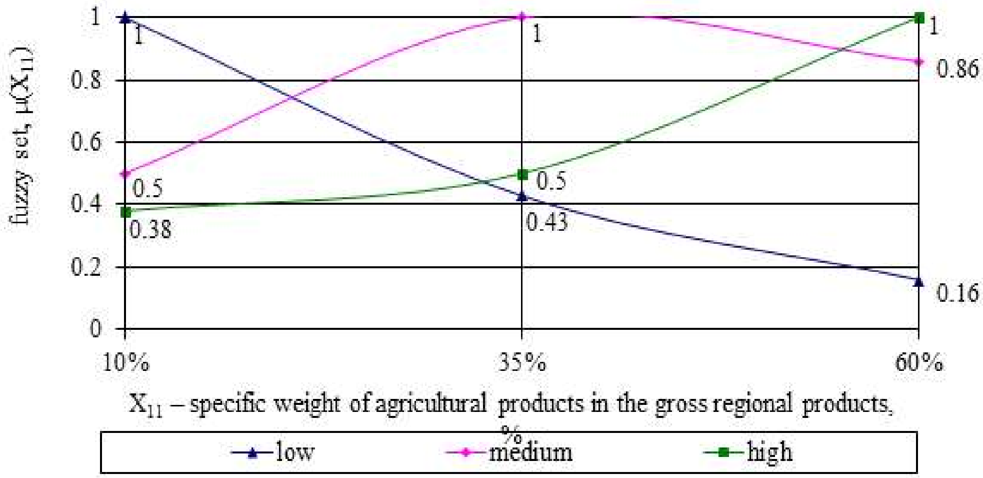


Fig. 2. Membership functions for the input parameter "specific weight of agricultural products in the gross regional product"

Source: *authors' own research*

In accordance with this methodology, the matrices of pairwise comparisons and degrees of belonging to the model were determined, as well as the belonging functions were constructed for other input parameters for assessing the economic and ecological potential of the agricultural sector of the region [5].

The next stage of building a model for assessing the level of the economic and ecological potential of the agricultural sector of the region is the formation of a knowledge base with the help of experts on the relations of vague terms of input and output linguistic parameters.

Fuzzy knowledge bases corresponding to ratio (2) are given in table. 3. Each row of the table corresponds to one rule < If - then >. The connection between linguistic variables within one rule is carried out by the AND logical operation. Within the limits of one knowledge base, linguistic rules-strings are linked by the logical OR operation. In fuzzy knowledge bases, the symbol "–" denotes variables that can take arbitrary values without violating the truth of the corresponding rule.

The assessment of the level of economic and ecological potential of the agricultural sector of the region (U) and intermediate output variables (X_1 - X_4) involves the use of the following term-sets: <low>; < below average >; < medium >; < above average > ; < tall >.

Given in the table. 3 linguistic statements correspond to a system of fuzzy logical equations, which have the form:

$$\mu^{H}(Y)=\mu^{H}(X_1)\cdot\mu^{H}(X_2)\cdot\mu^{H}(X_3)\cdot\mu^{H}(X_4)\vee\mu^{H}(X_1)\cdot\mu^{\text{н}C}(X_2)\cdot\mu^{H}(X_3)\cdot\mu^{\text{н}C}(X_4)\vee$$
$$\vee\,\mu^{\text{н}C}(X_1)\cdot\mu^{H}(X_2)\cdot\mu^{\text{н}C}(X_3)\cdot\mu^{H}(X_4)\vee\mu^{H}(X_1)\cdot\mu^{\text{н}C}(X_2)\cdot\mu^{\text{н}C}(X_3)\cdot\mu^{H}(X_4)\vee$$
$$\vee\,\mu^{H}(X_1)\cdot\mu^{H}(X_2)\cdot\mu^{H}(X_3)\cdot\mu^{\text{н}C}(X_4)\vee$$

(11)

$$\mu^{H}(Y)=\mu^{\text{н}C}(X_1)\cdot\mu^{\text{н}C}(X_2)\cdot\mu^{H}(X_3)\cdot\mu^{\text{н}C}(X_4)\vee\mu^{H}(X_1)\cdot\mu^{\text{н}C}(X_2)\cdot\mu^{\text{н}C}(X_3)\cdot\mu^{\text{н}C}(X_4)\vee$$
$$\vee\,\mu^{\text{н}C}(X_1)\cdot\mu^{\text{н}C}(X_2)\cdot\mu^{\text{н}C}(X_3)\cdot\mu^{\text{н}C}(X_4)\vee\mu^{\text{н}C}(X_1)\cdot\mu^{C}(X_2)\cdot\mu^{\text{н}C}(X_3)\cdot\mu^{C}(X_4)\vee$$
$$\vee\,\mu^{\text{н}C}(X_1)\cdot\mu^{C}(X_2)\cdot\mu^{C}(X_3)\cdot\mu^{\text{н}C}(X_4)\vee$$

(12)

$$\mu^{H}(Y)=\mu^{C}(X_1)\cdot\mu^{C}(X_2)\cdot\mu^{\text{н}C}(X_3)\cdot\mu^{C}(X_4)\vee\mu^{C}(X_1)\cdot\mu^{\text{н}C}(X_2)\cdot\mu^{C}(X_3)\cdot\mu^{C}(X_4)\vee$$
$$\vee\,\mu^{C}(X_1)\cdot\mu^{C}(X_2)\cdot\mu^{C}(X_3)\cdot\mu^{C}(X_4)\vee\mu^{C}(X_1)\cdot\mu^{C}(X_2)\cdot\mu^{C}(X_3)\cdot\mu^{\text{н}C}(X_4)\vee$$
$$\vee\,\mu^{\text{в}C}(X_1)\cdot\mu^{\text{в}C}(X_2)\cdot\mu^{C}(X_3)\cdot\mu^{C}(X_4)\vee$$

(13)

$$\mu^{H}(Y)=\mu^{\text{в}C}(X_1)\cdot\mu^{\text{в}C}(X_2)\cdot\mu^{C}(X_3)\cdot\mu^{C}(X_4)\vee\mu^{C}(X_1)\cdot\mu^{\text{в}C}(X_2)\cdot\mu^{C}(X_3)\cdot\mu^{\text{в}C}(X_4)\vee$$
$$\vee\,\mu^{\text{в}C}(X_1)\cdot\mu^{\text{в}C}(X_2)\cdot\mu^{\text{в}C}(X_3)\cdot\mu^{\text{вС}}(X_4)\vee\mu^{B}(X_1)\cdot\mu^{\text{в}C}(X_2)\cdot\mu^{\text{в}C}(X_3)\cdot\mu^{\text{в}C}(X_4)\vee$$
$$\vee\,\mu^{\text{в}C}(X_1)\cdot\mu^{B}(X_2)\cdot\mu^{\text{в}C}(X_3)\cdot\mu^{\text{в}C}(X_4)\vee$$
(14)

$$\mu^{H}(Y)=\mu^{\text{в}C}(X_1)\cdot\mu^{B}(X_2)\cdot\mu^{\text{в}C}(X_3)\cdot\mu^{B}(X_4)\vee\mu^{B}(X_1)\cdot\mu^{B}(X_2)\cdot\mu^{\text{в}C}(X_3)\cdot\mu^{\text{в}C}(X_4)\vee$$
$$\vee\,\mu^{\text{в}C}(X_1)\cdot\mu^{\text{в}C}(X_2)\cdot\mu^{B}(X_3)\cdot\mu^{\mathrm{B}}(X_4)\vee\mu^{B}(X_1)\cdot\mu^{\text{в}C}(X_2)\cdot\mu^{B}(X_3)\cdot\mu^{B}(X_4)\vee$$
$$\vee\,\mu^{B}(X_1)\cdot\mu^{B}(X_2)\cdot\mu^{B}(X_3)\cdot\mu^{B}(X_4)\vee$$
(15)

Table 3 Knowledge base on the level of economic and ecological potential of the agricultural sector of the region

Input parameters (variable)				Output variable
If				then
X_1	*X_2*	*X_3*	*X_4*	*y*
L	L	L	L	Low (L)
L	lM	L	lM	
lM	H	lM	H	
H	lM	lM	H	
H	H	H	lM	
lM	lM	H	lM	Lower than medium (lM)
H	lM	lM	lM	
lM	lM	lM	lM	
lM	M	lM	M	
lM	M	M	lM	
M	M	lM	M	medium (M)
M	lM	M	M	
M	M	M	M	
M	M	M	lM	
hM	hM	M	M	
hM	hM	M	M	Higher than medium (hM)
M	hM	M	hM	
hM	hM	hM	hM	
H	hM	hM	hM	
hM	H	hM	hM	
hM	H	hM	H	high (H)
H	H	hM	hM	
hM	hM	H	H	
H	hM	H	H	
H	H	H	H	

Source: *own research according to experts*

In these functions, the sign " $\vee$ " means the logical operation "OR" and "$\cdot$" means the logical operation "AND". When calculating the initial parameters, the minimum value is selected from the logical record of all membership functions grouped by the AND operation ($\cdot$), and the maximum value is selected from all membership functions grouped by the OR operation ($\vee$).

For other intermediate initial parameters of the assessment of the level of the economic and ecological potential of the agricultural sector of the region, knowledge bases were formed in a similar way [17;18;19;22].

The final stage of model development is the process of defuzzification i.e. the transformation of fuzzy information into an understandable form. There are various methods of defuzzification, the most common of which is finding the "center of gravity" of a flat figure bounded by a membership function of a fuzzy set and a horizontal coordinate [10]. Defuzzification according to this method allows quantitative assessment of the level economic and ecological potential of the agricultural sector of the region at given values of influence factors.

According to this method, defuzzification makes it possible to obtain a quantitative assessment of the level of the economic and ecological potential of the agricultural sector of the region at the given values of the influencing factors:

$$\mathrm{EE}P_{AIS} = (X_1, \mathrm{X}_2, \mathrm{X}_3, \mathrm{X}_4) = \frac{\sum_{i=1}^{n} \mathrm{EE}P_{AIS}{}^{d_i} \cdot \mu_{d_i}(\mathrm{EE}Pais)}{\sum_{i=1}^{n} \mu_{d_i}(\mathrm{EE}P_{AIS})}, \quad (16)$$

$\mathrm{EE}P_{AIS} -$ the economic and ecological potential of agricultural industrial sector

where n is the number of fuzzy terms for estimating the *EEP* variable of the *agricultural sector* ; d_i is the name of the ith term, $i = \overline{1,1}$; $\mathrm{EE}P_{AIS}$ – the degree of appropriateness of the level of the economic and ecological potential of the agricultural sector of the region to the term d_i .

Therefore, a qualitative assessment of the level of economic and ecological potential of the agricultural sector of the region will have the following form:

$$\mathrm{EE}P_{AIS} = (X_1, X_2, X_3, \mathrm{X}_4) = \left\{\frac{\mu^{d_1}(\mathrm{EE}P_{AIS})}{q_1}, \frac{\mu^{d_2}(\mathrm{EE}P_{AIS})}{q_2} \dots \frac{\mu^{d_m}(\mathrm{EE}P_{AIS})}{q_n}\right\}, \quad (17)$$

where q_i is the quantitative value that corresponds to the term d_i .

Based on the chosen method of defuzzification (center of gravity), the fuzzy set corresponds to the following quantitative assessment of the level of economic and ecological potential of the agricultural sector of the region:

$$\mathrm{EE}P_{AIS} = \frac{\sum_{i=1}^{n}\left[\underline{\mathrm{EE}P_{AIS}} + (i-1)\frac{\overline{\mathrm{EE}Pais} - \underline{EEPais}}{n-1}\right]\mu_{d_i}(\mathrm{EE}P_{AIS})}{\sum_{i=1}^{n} \mu_{d_i}(\mathrm{EE}P_{AIS})}, \quad (18)$$

where $\mathrm{EE}P_{AIS}$ – the lowest (highest) value of the level of economic and ecological potential of the agricultural sector of the region.

In this case, to measure the level of the economic and ecological potential of the agricultural sector of the region, it is proposed to use relative units, where $\mathrm{EE}P_{AIS} = 0$, $\mathrm{EE}P_{AIS} = 1$.

Thus, the developed model makes it possible to assess not only the current state of the economic and ecological potential of the regional agro-industrial complex, but also makes it possible to create an effective decision-making system that will help the management of the region to make balanced decisions regarding the effective functioning of the agro-industrial complex from the standpoint of its economic and ecological capabilities.

Under the modern dynamic conditions of economic development, a rapid change in the values of the input parameters of the model is a certain problem when assessing the economic and ecological potential of the agricultural sector of the region. Therefore, an important advantage of such an assessment is its flexibility, that is, the ability of the model to take into account possible changes in the input indicators that affect the assessment of the potential of the agro-industrial complex.

DISCUSSION

In the context of today rapidly evolving economic conditions, the frequent fluctuations in the values of input parameters pose a challenge when assessing the economic and ecological potential of a region's agricultural sector. Therefore, a key advantage of such assessments is their flexibility—the model's capacity to accommodate changes in input indicators that influence the evaluation of the sector's potential.

The developed model addresses this issue by providing not only an assessment of the current state of the economic and ecological potential but also by establishing an effective decision-making system. This system aids regional management in making well-informed decisions that enhance the operational efficiency of the agricultural sector, considering both its economic and ecological dimensions.

CONCLUSIONS

The results of the study made it possible to identify the most influential parameters and group them by four main components of the economic and environmental potential of the agricultural sector of the region. The proposed methodical approach allows taking into account not only quantitative indicators, but also qualitative ones, which can be assessed with the help of linguistic terms, which provides reliable information for timely adoption of appropriate managerial decisions on the flexibility of the economic and environmental potential of the agricultural sector of the region under adverse internal or external influences.

Given the difficult conditions in which our country finds itself today, ensuring sustainable development of regions requires the search for effective mechanisms to improve their functioning. The agro-industrial complex remains one of the strategically important and promising sectors of the economy. Thus, the process of formation and implementation of the main strategic directions of regional development requires the development of a methodological approach to assess the economic and environmental potential of the agricultural sector, which would take into account various indicators that affect it, as well as allow prompt and adequate response to external and internal changes.

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