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Evaluation of the efficiency of agrarian institutions of higher education of Ukraine using the DEA method

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► **Abstract.** The relevance of the study is determined by the need to perfect the evaluation of the efficiency of scientific and educational activities of the country's higher education institutions and determine the causes of inefficiency. The purpose of this study was to improve the evaluation of the efficiency of scientific publication activities of agrarian higher education institutions of Ukraine using the Data Envelopment Analysis method. The study was conducted according to the general heuristic method, the authors also employed mathematical and statistical methods of processing and analysis of input and output data, computer methods for the implementation of research tasks and abstract-logical methods for determining the degree of relevance, formulation of conclusions. The study substantiated the feasibility of using the non-parametric method of Data Envelopment Analysis to evaluate the efficiency of the scientific and educational activities of higher education institutions, as well as the feasibility of using Voluntary Retirement Services and Compulsory Retirement Service models, which are input-oriented, to evaluate the technical, purely technical, large-scale efficiency of scientific publication activity. Based on statistical information for 2020–2021, the technical, purely technical, large-scale efficiency of the scientific publication activity of 38 agricultural institutions of higher education of Ukraine were evaluated using the Data Envelopment Analysis method. According to the results of calculations, 18% of the educational institutions under study have the maximum value of technical and large-scale efficiency. The average technical efficiency is 0.6, the average pure technical efficiency – 0.7, and the average scale efficiency – 0.85. The analysis of the estimated values of relative efficiency allowed identifying the reasons for the inefficiency of each higher education institution under study, including suboptimal use of educational resources and an unbalanced scale of activity. Based on the study results, a rating of agrarian institutions of higher education in Ukraine in terms of the efficiency of scientific publication activities was compiled, which can be used as an addition to conventional ratings for analysing scientific and educational activities. The results of this study can be used to rank higher educational institutions by efficiency, to find the reasons for their ineffective activities

► **Keywords:** agrarian institutions of higher education; Data Envelopment Analysis method; technical efficiency; pure technical efficiency; large-scale efficiency; rating

► Introduction

An objective assessment of the efficiency of the scientific and educational activities of higher education institutions (HEI) in Ukraine is necessary for all participants in the market of educational services: stakeholders of educational services, managers of higher education institutions, and supervisory bodies for ensuring the quality of higher education. It is important to use efficiency assessment methods that allow considering the influence of multiple factors on multiple activity results, are based on open objective statistical information and do not depend on the opinions and judgments of experts, and also allow determining the causes of inefficiency. The relevance of this study is conditioned upon the need to perfect

the evaluation of the efficiency of scientific and educational activities of the HEI of Ukraine, considering the conditions that affect the objectivity of the evaluation and determining the causes of inefficiency. There is a wide variety of performance evaluation methods. Choosing a method for evaluating efficiency is an important research task. M. Dubinina *et al.* (2023) provided an analysis of the current methods of evaluating efficiency, including non-parametric methods that allow evaluating efficiency based on the impact analysis of a set of input factors (resources) on a set of output factors (results of activity). The DEA method is a non-parametric method of assessing the relative efficiency of any complex socio-

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economic objects. Charnes *et al.* (1978) used the term “Decision-making unit” (DMU) to emphasize the fact that the DEA method evaluates the efficiency of any decision-making organization. The advantages of using the DEA method are described by Ya. Dolgikh (2020), the key to which are the ability to comprehensively evaluate efficiency, as well as the ability to identify the causes of inefficient activity and provide reasonable recommendations for increasing efficiency to the maximum level. The DEA method allows for obtaining a remote performance assessment based on open statistical information.

The DEA method is widely used in the foreign practice of evaluating the performance of various business entities. There are special professional websites that contain software developed for DEA models. For instance, the site “Data Envelopment Analysis Online Software” (2023). Many statistical programs offer DEA calculations. For example, the software environment for processing data arrays R includes the “dear” program package for solving practical problems with a wide range of DEA models (Coll-Serrano *et al.*, 2018; Lotfi *et al.*, 2020).

Many studies by foreign authors cover the theoretical and practical aspects of the application of the DEA method for evaluating the efficiency of various business entities. A. Emrouznejad *et al.* (2008) provides an extended analysis of works on the application of the DEA method from 1978-2007. The article of A. Charnes *et al.* (1978) are one of the most famous scientific studies, which became the basis of many scientific papers. According to data for 1987-2020, 301 papers covering the application of the DEA method in education were published (Data Envelopment Analysis..., 2023). Scientific studies on the application of the DEA method in education are divided into such areas as the application of the DEA method to evaluate the efficiency of schools and universities. These areas of research determine the variety of models used, which is primarily conditioned upon various combinations of input and output data. One of the first scientific studies on the application of the DEA method in education is the article by A. Bessent *et al.* (1982), which evaluated the efficiency of educational activities of schools.

Among the latest foreign studies covering the application of the DEA method for evaluating the efficiency of HEIs, one can note the studies of D. Mirasol-Cavero and L. Ocampo (2023), who were engaged in programming fuzzy preferences in data analysis for the evaluation of university departments. Unfortunately, in Ukraine, modern modelling methods are rarely used to analyse the efficiency of scientific and educational activities.

The scientific originality of this study is to determine the specific features of using the DEA method to assess the efficiency of scientific publication activities of agricultural universities in Ukraine.

The purpose of the study was to evaluate and analyse the efficiency of the scientific publication activities of agrarian educational HEIs, to identify the causes of inefficiency.

► Literature review

A. Bessent *et al.* (1982) evaluated the efficiency of the educational activities of schools. The paper identified such advantages of the DEA method as evaluating efficiency based on multiple performance results, the absence of the need to set a functional form for a production function, and the ability to identify sources of inefficiency. The studies of T. Stal *et al.* (2023), A. Athanassopoulos & E. Shale (1997), and G. Madden *et al.* (1997) can be noted among the first scientific papers using the DEA method to evaluate the efficiency of the educational and scientific activities of universities. Among the scientific articles published recently, the paper by D. Mirasol-Cavero and L. Ocampo (2023) can be noted, which proposes the application of the FPP-DEA model that allows the processing of missing and imprecise initial data. The FPP-DEA model has been tested in a higher education institution in the Philippines. The study by T. Tran *et al.* (2023) examines the efficiency of 172 Vietnamese HEIs during 2012-2016 using the DEA method.

The authors compare the efficiency of public and private, mono- and multidisciplinary, non-autonomous, and autonomous HEIs that carry out international activities and those that do not have such activities. It is concluded that public universities tend to be less efficient than their counterparts in the private sector. Universities with international programs have higher performance indicators than those that do not have international programs.

Zh. Ma *et al.* (2021) proposed a DEA model for evaluating the performance of mixed-type DMUs. The model was tested to evaluate the efficiency of interdisciplinary scientific research by teachers at the University of Inner Mongolia. R.S. Tavares *et al.* (2021) suggest the use of the DEA method for evaluating the efficiency of the educational, scientific, and financial activities of universities. The proposed model was tested in 45 Brazilian federal universities. The paper by R. Mammadov and Ah. Aypay (2020) identifies factors that influence the efficiency of research universities in Turkey. G. Zhang *et al.* (2020) proposed the application of the DEA method to evaluate the efficiency of resource use by HEIs in the provinces of China. Changes in efficiency were evaluated, and suggestions for improving the current higher education system were provided.

Among the latest works of Ukrainian authors, which describe the use of the DEA method for evaluating the efficiency of educational activities, one can note the study by I. Lesik *et al.* (2022). The paper analyses some factors that affect the efficiency of the education system in Ukraine using the DEA method. The study was conducted in 24 regions of Ukraine. The input indicator was the number of students who entered the university for the first time, the output indicators were the following: the number of people who received a certificate of complete general secondary education, the number of people who completed the External Independent Evaluation, the average cost of studying at the university

per year, UAH, the number of students studying with budget funds. The next study that deserves attention is the paper by O. Omelianenko (2022), which provides a methodological approach to the application of the DEA method to evaluate the efficiency of spending budget funds on various social programs, including secondary education. In the paper by A. Shender (2013), the efficiency of the use of educational resources in different regions of Ukraine was established using the DEA method.

Based on the analysis of the obtained results, problematic issues that need to be solved were identified, and measures of the regional policy of the market of educational services were recommended. The analysis of publications covering the application of the DEA method in education shows that the issue of the application of the DEA method for evaluating the efficiency of HEIs in Ukraine and analysing the causes of ineffective activity has been understudied.

► Materials and methods

The following methods were used during the study: 1) generalized heuristic method; 2) statistical research (for collection, processing, and analysis of input and output data); 3) economic-mathematical modelling (application of the Voluntary Retirement Services (VRS) and Compulsory Retirement Service (CRS) models of the DEA method to evaluate the technical, purely technical, large-scale efficiency of scientific publication activities); 4) special (non-parametric DEA method, according to which the relative efficiency of each researched DMU (Decision-Making Units) is evaluated by solving linear programming problems; a benchmarking method for comparing the performance of researched DMUs with reference ones that have maximum efficiency); 5) computer (development of a program in the Visual Basic for Applications language for Microsoft Excel to perform calculations according to DEA models); 6) abstract-logical (to assess the degree of relevance of the study, to formulate conclusions).

The DEA method evaluates the relative efficiency of each business entity of the same type (DMU) o_k , $k=1, \bar{K}$ any complex socio-economic system, the activity of which is characterized by vectors of input $X_k=(x_{k1}, x_{k2}, \dots, x_{km})$ and output $Y_k=(y_{k1}, y_{k2}, \dots, y_{kn})$ variables. Input variables can be resources used in economic activity, output resources – results of economic activity (amount of produced goods, services). Entities that produce the maximum number of goods or render the maximum number of services for a certain number of resources have the maximum relative efficiency and form the so-called efficiency limit in the space of input-output variables. The relative efficiency of entities that do not belong to the efficiency boundary is evaluated by the degree of distance from it – the further, the smaller the value of relative efficiency.

The DEA method is used to calculate technical efficiency (TE), pure technical efficiency (PTE) and scale efficiency (SE). Pure technical efficiency is calculated according to the VRS model, which considers

the variable effect of the scale of economic activity. Technical efficiency is calculated using the CRS model, which considers the constant effect of the scale of activity. Large-scale efficiency is calculated as the ratio of technical efficiency to pure technical efficiency. Determining the values of the specified types of efficiency allows for a complete analysis of economic activity. There is also a distinction between DEA models that are input-oriented and output-oriented. Input-oriented models minimize the vector of input variables with a fixed vector of output variables, while output-oriented models maximize the vector of output variables with a fixed vector of input variables.

Estimation of technical efficiency according to the input-oriented CRS model is carried out by solving the following linear programming problem (Charnes *et al.*, 1978):

$$\min_{E, \lambda_1, \lambda_2, \dots, \lambda_k} E \quad (1)$$

$$EX_0 \geq \sum_{k=1}^K \lambda_k X_k, \quad Y_0 \leq \sum_{k=1}^K \lambda_k Y_k \quad (2)$$

$$\lambda_k \geq 0 \quad (k=\bar{1}, \bar{K}) \quad (3)$$

where E is the input technical efficiency; λ_k is the unknown coefficients to be determined; K is the number of DMUs that are compared in efficiency; X_0 is the vector of input variables of the DMU being analysed; Y_0 is the vector of the output variables of the DMU being analysed; X_k is the vector of input variables of the k^{th} DMU; Y_k is the vector of output variables of the k^{th} DMU.

Estimation of pure technical efficiency according to the input-oriented VRS model is carried out by solving problems (1)-(3) with the addition of the following constraint to the system of constraints (2), (3) (Banker *et al.*, 1984):

$$\sum_{k=1}^K \lambda_k = 1 \quad (4)$$

Correct solution of problem (1)-(4) is possible if the following non-degeneracy condition is met (Cooper *et al.*, 2006):

$$K \geq \max\{m \times n; 3(n+m)\}, \quad (5)$$

where n is the number of output variables; m is the number of input variables.

The application of the DEA method to assess the effectiveness of the scientific publication activities of the agricultural higher education institutions of Ukraine was carried out in the following stages: 1) identification of the subjects of economic activity, the effectiveness of which is subject to evaluation (agrarian HEIs), as well as the object of the study (scientific publication activity); 2) selection of a modelling apparatus (non-parametric efficiency assessment methods, DEA method), DEA method models for relative efficiency assessment (VRS-, CRS-, input-oriented); 3) determination of input and output data for the construction of DEA models, which

consider the specific features of the object under study, satisfy the specific features of the application of the DEA method, the condition of non-degeneracy. The statistical database of the values of the input data, namely the number of scientific and pedagogical workers (SPWs) of the HEIs under study, the amount of funding of the HEIs under study in 2020, the amount of income to the special fund per SWP of the HEIs under study in 2020 was formed according to the information on the official website of the Ministry of Education and Science of Ukraine (Ministry of Education and Science..., 2023). The statistical base of the values of the initial data, namely the number of Scopus publications by the SWPs of the HEIs under study in 2021, the number of citations of the SWPs of the HEIs in 2021, the Hirsch index of the SWPs of the HEIs in 2021, the difference in the Hirsch index (2021-2020) formed based on the information of the ranking of universities by Scopus indicators of 2021, published on the website "Education in Ukraine and abroad" (Education in Ukraine..., 2023); 4) the implementation of the

research task, namely the determination of the values of technical, pure technical, large-scale efficiency, the nature of the return on the scale of activity, the analysis, and evaluation of the solutions found, the provision of recommendations to increase the effectiveness of the scientific and educational activities of the agrarian HEIs under study, the determination of areas for further scientific research.

► Results

► **Determination of the subjects, the object of the study, the effectiveness of which is subject to evaluation.** HEIs of Ukraine, namely universities, academies, institutes with an agrarian orientation of scientific and educational activities, were chosen as entities of economic activity to be evaluated according to the DEA method. Among these HEIs, 38 were selected, which carry out educational and scientific activities in the following fields: "Agrarian sciences and food", "Production and technologies", "Natural sciences". Table 1 shows a sample of DMUs – agrarian HEIs of Ukraine selected for the study.

Table 1. Agrarian HEIs of Ukraine under study

| No. DMU | HEI | No. DMU | HEI |
|---------|-----------------------------------------------------------------------------------------|---------|---------------------------------------------------------------|
| 1 | Bila Tserkva National Agrarian University | 20 | Odesa State Agrarian University |
| 2 | Vinnitsia National Agrarian University | 21 | Odesa State Ecological University |
| 3 | Uzhhorod National University | 22 | I. I. Mechnykov Odesa National University |
| 4 | Luhansk Taras Shevchenko National University | 23 | Podillia State University |
| 5 | Dnipro State Agrarian and Economic University | 24 | Polissia National University |
| 6 | Oles Honchar Dnipro National University | 25 | Poltava State Agrarian University |
| 7 | Zaporizhzhia National University | 26 | Vasyl Stefanyk Precarpathian National University |
| 8 | West Ukrainian National University | 27 | Sumy National Agrarian University |
| 9 | Lutsk National Technical University | 28 | Lesya Ukrainka Volyn National University |
| 10 | Stepan Gzhytskyi National University of Veterinary Medicine and Biotechnologies of Lviv | 29 | Volodymyr Dahl East Ukrainian National University |
| 11 | Lviv National Environmental University (Lviv National Agrarian University) | 30 | Dmytro Motornyi Tavria State Agrotechnological University |
| 12 | Bogdan Khmelnytsky Melitopol State Pedagogical University | 31 | Ternopil Ivan Puluj National Technical University |
| 13 | Mykolaiv National Agrarian University | 32 | Uman National University of Horticulture |
| 14 | Ukrainian National Forestry University | 33 | O. M. Beketov National University of Urban Economy in Kharkiv |
| 15 | National Technical University "Kharkiv Polytechnic Institute" | 34 | Kherson State Agrarian and Economic University |
| 16 | Chernihiv Polytechnic National University | 35 | Khmelnytskyi National University |
| 17 | National University of Life and Environmental Sciences of Ukraine | 36 | Central Ukrainian National Technical University |
| 18 | National University of Water and Environmental Engineering | 37 | Cherkasy State Technological University |
| 19 | National University of Food Technologies | 38 | Yuriy Fedkovych Chernivtsi National University |

Source: Ministry of Education and Science of Ukraine (2023)

► **Definition of the simulation apparatus, models of the DEA method for efficiency assessment.** The non-parametric DEA method was chosen to evaluate the effectiveness of the scientific and

journalistic activity of agrarian HEIs of Ukraine. The subject of economic activity is efficient if, according to the solution of problems (1)-(3) or (1)-(4), the input technical efficiency is equal to 1 and the binary

values are equal to zero. For efficient economic entities, the T.C. Koopmans (1951) optimum is achieved, at which the existing level of resource consumption ensures the maximum possible results of activity. This suggests that the combination of resources is optimal. Non-zero values of dual estimates indicate that the subject of economic activity is inefficient.

An economic entity that is efficient according to the CRS model is also efficient according to the VRS model and operates in the most productive scale, the CRS (Constant Return to Scale) zone (Bogetoft & Otto, 2013). The scale efficiency value of such an entity is $SE=1$. If $SE<1$, then the scale of activity of such an economic entity is inefficient due to too large or too small scale of activity. The following zones of scale inefficiency are distinguished: with decreasing return to scale (DRS) and with increasing return to scale (IRS). If the subject works in the DRS zone, then the scale of its activity is too large, and if in the IRS zone, it is too small from the optimal one. It is possible to determine the nature of returns to scale (RTS) when solving problems (1)-(3). If according to the received solution $\sum_{k=1}^K \lambda_k^* < 1$, then the subject works in the IRS zone, if $\sum_{k=1}^K \lambda_k^* > 1$, then in the DRS zone (Bogetoft & Otto, 2011).

At the stage of clarification and detailing of the research task, input-oriented VRS and CRS models of relative efficiency assessment were chosen. Determining the relative efficiency according to the

VRS and CRS models will allow a full analysis of efficiency to identify the causes of inefficient activity. The reasons for inefficient work can include the irrational use of resources and the wrong scale of activity. The chosen orientation of input-oriented models allows providing recommendations for achieving the maximum efficiency of the scientific and journalistic activity of the HEIs under study through the optimization of the resources used. This approach to optimization is appropriate if the indicators of the results of scientific publication activities are sufficient, are limited by the contracts of SWPs, and it is necessary to save the resources spent. Input-oriented DEA models are more convenient for educational process managers, as management has more opportunities to control input resources and adjust them.

► **Determination of input and output values for performance evaluation.** The specified stage of the study included the determination of input and output variable models, namely, the formation of the composition of factors considering the specific features of the object under study, the verification of the condition of non-degeneracy. Statistical data of input factors were obtained from the official website of the Ministry of Education and Science of Ukraine (2023), output factors – from the website “Education in Ukraine and abroad” (2023). The values of the input and output variables are presented in Table 2.

Table 2. Input and output data for building DEA models

| No. DMU | Input data | | | Output data | | | |
|---------|--------------|----------------------------------------------|-------------------------------------------------------------------------------|-----------------------------------------------------------------|-------------------------------------------------------|------------------------------------------|-------------------------------------|
| | SWPs. people | Financing of HEIs in 2020 ¹ . UAH | Income to the special fund per one SWP of the HEIs in 2020 ² . UAH | Number of Scopus publications by SWPs of the HEIs in 2021. pcs. | Number of citations of SWPs of the HEIs in 2021. pcs. | Hirsch Index of SWPs of the HEIs in 2021 | Hirsch index difference (2021-2020) |
| 1 | 376 | 89 194 277 | 5 004 | 173 | 590 | 13 | 2 |
| 2 | 327 | 69 255 597.38 | 13 456 | 206 | 515 | 10 | 2 |
| 3 | 1 285 | 206 950 420.3 | 1 485 | 2 673 | 14 444 | 43 | 3 |
| 4 | 401 | 80 868 766 | 271 | 193 | 852 | 14 | 1 |
| 5 | 327 | 68 290 648.29 | 9 906 | 280 | 765 | 11 | 1 |
| 6 | 826 | 244 447 860.6 | 2 112 | 4 262 | 18 456 | 46 | 1 |
| 7 | 665 | 131 734 756 | 1 043 | 972 | 2 374 | 21 | 1 |
| 8 | 686 | 113 593 894.1 | 2 211 | 961 | 2 765 | 21 | 4 |
| 9 | 413 | 107 988 364.3 | 6 356 | 561 | 1 058 | 13 | 1 |
| 10 | 412 | 86 775 294 | 518 | 286 | 1 970 | 22 | 2 |
| 11 | 338 | 82 024 309.75 | 2 194 | 233 | 722 | 9 | 2 |
| 12 | 278 | 63 836 469 | 5 831 | 174 | 536 | 11 | 5 |
| 13 | 352 | 83 015 800 | 15 337 | 205 | 517 | 12 | 4 |
| 14 | 314 | 81 628 951 | 11 321 | 363 | 3 292 | 26 | 5 |
| 15 | 1 387 | 370 456 684 | 4 206 | 4 890 | 19 915 | 48 | 3 |
| 16 | 260 | 102 850 837 | 12 579 | 467 | 1 825 | 19 | 19 |
| 17 | 1 210 | 460 500 086.1 | 8 055 | 1 730 | 6 645 | 32 | 4 |
| 18 | 549 | 137 998 203.1 | 4 003 | 722 | 2 402 | 19 | 4 |
| 19 | 577 | 171 116 283.3 | 1 432 | 717 | 3 243 | 25 | 3 |
| 20 | 141 | 28 348 087.48 | 963 | 34 | 64 | 6 | 6 |

Table 2, Continued

| No. DMU | Input data | | | Output data | | | |
|---------|--------------|----------------------------------------------|-------------------------------------------------------------------------------|-----------------------------------------------------------------|-------------------------------------------------------|------------------------------------------|-------------------------------------|
| | SWPs. people | Financing of HEIs in 2020 ¹ . UAH | Income to the special fund per one SWP of the HEIs in 2020 ² . UAH | Number of Scopus publications by SWPs of the HEIs in 2021. pcs. | Number of citations of SWPs of the HEIs in 2021. pcs. | Hirsch Index of SWPs of the HEIs in 2021 | Hirsch index difference (2021-2020) |
| 21 | 168 | 48 057 414 | 2 096 | 296 | 1 631 | 17 | 1 |
| 22 | 759 | 116 341 560.4 | 7 170 | 3 916 | 25 987 | 67 | 5 |
| 23 | 199 | 56 214 057 | 17 623 | 101 | 143 | 6 | 6 |
| 24 | 356 | 70 454 941 | 1 909 | 244 | 546 | 11 | 3 |
| 25 | 325 | 70 359 641 | 4 467 | 243 | 418 | 9 | 3 |
| 26 | 876 | 127 778 537 | 10 042 | 1 152 | 11 944 | 47 | 5 |
| 27 | 385 | 118 660 074.1 | 7 355 | 463 | 1 932 | 20 | 3 |
| 28 | 772 | 151 417 840 | 6 683 | 975 | 7 082 | 32 | 2 |
| 29 | 435 | 125 405 236 | 996 | 943 | 3 498 | 21 | 5 |
| 30 | 318 | 83 029 307 | 3 174 | 281 | 668 | 12 | 5 |
| 31 | 416 | 85 079 178 | 2 108 | 910 | 2 832 | 17 | 2 |
| 32 | 295 | 76 091 055.5 | 1 407 | 211 | 306 | 9 | 4 |
| 33 | 499 | 109 467 191.9 | 11.081 | 597 | 1 440 | 17 | 3 |
| 34 | 216 | 47 324 793 | 2 072 | 123 | 349 | 10 | 4 |
| 35 | 544 | 104 312 584.6 | 2 234 | 684 | 2 812 | 19 | 0 |
| 36 | 311 | 74 986 147.68 | 341 | 261 | 606 | 10 | 2 |
| 37 | 345 | 72 738 483 | 193 | 294 | 1 093 | 20 | 14 |
| 38 | 1 035 | 178 450 009.4 | 539 | 3 995 | 20 227 | 64 | 3 |

Note: ¹except for 1) funding to ensure social benefits and other expenses according to the legislation; 2) a reserve, except for added expenses related to the increase in the official salary (rate) of an employee of the first tariff category, which was not prescribed as of January 1 of the previous year;

²according to the results of scientific and scientific and technical works under international cooperation projects, according to the results of scientific and scientific and technical works under economic contracts and according to the results of the provision of scientific services per one SWP according to the principal place of employment

Source: Ministry of Education and Science of Ukraine (2023), Education in Ukraine and abroad (2023)

The selected variables reflect the relationship between the resources of HEIs and the results of scientific publication activities created on their basis. When forming the composition of input and output variables, the time factor is considered – the specified results of scientific publication activity are possible at least one year after the impact of the specified input factors. The performance of the condition (5) is verified as follows:

$$38 \geq \max\{3 \times 4; 3(3+4)\}; 38 \geq \max\{12; 21\}; 38 \geq 21.$$

Thus, condition (5) is being performed.

► **Efficiency evaluation results.** At the last stage of the study, the implementation of the research task, analysis, and evaluation of the found solutions were carried out.

Table 3 shows the results of the calculations of technical efficiency (*TE*), pure technical efficiency (*PTE*), scale efficiency (*SE*) and returns to scale (*RTS*).

Table 4 shows the summary efficiency evaluation indicators.

Table 3. Calculation results

| No. DMU | <i>TE</i> | <i>PTE</i> | <i>SE</i> | <i>RTS</i> | No. DMU | <i>TE</i> | <i>PTE</i> | <i>SE</i> | <i>RTS</i> |
|---------|-----------|------------|-----------|------------|---------|-----------|------------|-----------|------------|
| 1 | 0.3806 | 0.4524 | 0.8414 | Increasing | 20 | 1.0000 | 1.0000 | 1.0000 | Constant |
| 2 | 0.3493 | 0.5058 | 0.6906 | Increasing | 21 | 1.0000 | 1.0000 | 1.0000 | Constant |
| 3 | 0.5919 | 0.6332 | 0.9347 | Increasing | 22 | 1.0000 | 1.0000 | 1.0000 | Constant |
| 4 | 0.5614 | 0.8691 | 0.6459 | Increasing | 23 | 0.5468 | 0.7625 | 0.7172 | Increasing |
| 5 | 0.3637 | 0.5411 | 0.6722 | Increasing | 24 | 0.4117 | 0.5667 | 0.7264 | Increasing |
| 6 | 1.0000 | 1.0000 | 1.0000 | Constant | 25 | 0.3515 | 0.5238 | 0.6711 | Increasing |
| 7 | 0.4837 | 0.6001 | 0.8060 | Increasing | 26 | 0.6742 | 0.6847 | 0.9847 | Increasing |
| 8 | 0.4673 | 0.5565 | 0.8397 | Increasing | 27 | 0.5414 | 0.5460 | 0.9915 | Decreasing |
| 9 | 0.3406 | 0.5115 | 0.6658 | Increasing | 28 | 0.4759 | 0.4792 | 0.9930 | Increasing |

Table 3, Continued

| No. DMU | TE | PTE | SE | RTS | No. DMU | TE | PTE | SE | RTS |
|---------|--------|--------|--------|------------|---------|--------|--------|--------|------------|
| 10 | 0.8347 | 0.8736 | 0.9555 | Increasing | 29 | 0.7317 | 0.8349 | 0.8764 | Increasing |
| 11 | 0.3337 | 0.5130 | 0.6505 | Increasing | 30 | 0.5068 | 0.5641 | 0.8984 | Increasing |
| 12 | 0.5324 | 0.6027 | 0.8834 | Increasing | 31 | 0.5446 | 0.7172 | 0.7593 | Increasing |
| 13 | 0.4066 | 0.4718 | 0.8618 | Increasing | 32 | 0.4388 | 0.6413 | 0.6842 | Increasing |
| 14 | 0.9001 | 0.9138 | 0.9849 | Decreasing | 33 | 0.3816 | 0.4457 | 0.8562 | Increasing |
| 15 | 0.7167 | 1.0000 | 0.7167 | Decreasing | 34 | 0.6282 | 0.7415 | 0.8473 | Increasing |
| 16 | 1.0000 | 1.0000 | 1.0000 | Constant | 35 | 0.4770 | 0.5611 | 0.8501 | Increasing |
| 17 | 0.3322 | 0.3532 | 0.9403 | Increasing | 36 | 0.5126 | 0.9953 | 0.5150 | Increasing |
| 18 | 0.4249 | 0.4720 | 0.9001 | Increasing | 37 | 1.0000 | 1.0000 | 1.0000 | Constant |
| 19 | 0.6392 | 0.6519 | 0.9805 | Increasing | 38 | 1.0000 | 1.0000 | 1.0000 | Constant |

Source: according to authors' calculations

Table 4. Evaluation indicators

| Indicators | Calculated values | | |
|------------------------------|-------------------|--------|--------|
| | TE | PTE | SE |
| Number of effective ones | 7 | 8 | 7 |
| Percentage of effective ones | 18.42 | 21.05 | 18.42 |
| Average efficiency | 0.6022 | 0.6996 | 0.8511 |
| CRS | 7 | | |
| IRS | 28 | | |
| DRS | 3 | | |

Source: according to authors' calculations

The calculated values of relative efficiency allow making a rating of agrarian HEIs according to scientific publication activity. Table 5 shows

the rating of the HEIs under study by technical, pure technical efficiency of scientific publication activity.

Table 5. Evaluation indicators

| Rating of agrarian HEIs according to the CRS-input model | | | Rating of agrarian HEIs according to the VRS-input model | | |
|----------------------------------------------------------|----------|------|----------------------------------------------------------|-----------|------|
| No. DMU | TE (CRS) | Rank | No. DMU | PTE (VRS) | Rank |
| 6 | 1 | 1 | 6 | 1 | 1 |
| 16 | 1 | 1 | 15 | 1 | 1 |
| 20 | 1 | 1 | 16 | 1 | 1 |
| 21 | 1 | 1 | 20 | 1 | 1 |
| 22 | 1 | 1 | 21 | 1 | 1 |
| 37 | 1 | 1 | 22 | 1 | 1 |
| 38 | 1 | 1 | 37 | 1 | 1 |
| 14 | 0.9000 | 2 | 38 | 1 | 1 |
| 10 | 0.8347 | 3 | 36 | 0.9953 | 2 |
| 29 | 0.7317 | 4 | 14 | 0.9138 | 3 |
| 15 | 0.7167 | 5 | 10 | 0.8736 | 4 |
| 26 | 0.6742 | 6 | 4 | 0.8691 | 5 |
| 19 | 0.6392 | 7 | 29 | 0.8349 | 6 |
| 34 | 0.6282 | 8 | 23 | 0.7625 | 7 |
| 3 | 0.5919 | 9 | 34 | 0.7415 | 8 |
| 4 | 0.5614 | 10 | 31 | 0.7172 | 9 |
| 23 | 0.5468 | 11 | 26 | 0.6847 | 10 |
| 31 | 0.5446 | 12 | 19 | 0.6519 | 11 |
| 27 | 0.5414 | 13 | 32 | 0.6413 | 12 |
| 12 | 0.5324 | 14 | 3 | 0.6332 | 13 |
| 36 | 0.5126 | 15 | 12 | 0.6027 | 14 |

Table 5, Continued

| Rating of agrarian HEIs according to the CRS-input model | | | Rating of agrarian HEIs according to the VRS-input model | | |
|----------------------------------------------------------|----------|------|----------------------------------------------------------|-----------|------|
| No. DMU | TE (CRS) | Rank | No. DMU | PTE (VRS) | Rank |
| 30 | 0.5068 | 16 | 7 | 0.6001 | 15 |
| 7 | 0.4837 | 17 | 24 | 0.5667 | 16 |
| 35 | 0.4770 | 18 | 30 | 0.5641 | 17 |
| 28 | 0.4759 | 19 | 35 | 0.5611 | 18 |
| 8 | 0.4673 | 20 | 8 | 0.5565 | 19 |
| 32 | 0.4388 | 21 | 27 | 0.5460 | 20 |
| 18 | 0.4249 | 22 | 5 | 0.5411 | 21 |
| 24 | 0.4117 | 23 | 25 | 0.5238 | 22 |
| 13 | 0.4066 | 24 | 11 | 0.5130 | 23 |
| 33 | 0.3816 | 25 | 9 | 0.5115 | 24 |
| 1 | 0.3806 | 26 | 2 | 0.5058 | 25 |
| 5 | 0.3637 | 27 | 28 | 0.4792 | 26 |
| 25 | 0.3515 | 28 | 18 | 0.4720 | 27 |
| 2 | 0.3493 | 29 | 13 | 0.4718 | 28 |
| 9 | 0.3406 | 30 | 1 | 0.4524 | 29 |
| 11 | 0.3337 | 31 | 33 | 0.4457 | 30 |
| 17 | 0.3322 | 32 | 17 | 0.3532 | 31 |

Source: according to authors' calculations

Analysis of the calculated technical efficiency (*TE*) values in Table 3 allow concluding on the efficiency of resource use. The following HEIs had the highest technical efficiency (*TE*): Oles Honchar Dnipro National University, Chernihiv Polytechnic National University, Odesa State Agrarian University, Odesa State Ecological University, I.I. Mechnykov Odesa National University, Cherkasy State Technological University, Yuriy Fedkovych Chernivtsi National University. The minimum value of technical efficiency (*TE*) corresponded to the National University of Life and Environmental Sciences of Ukraine. The estimated value of $TE=0.33$ means that the use of involved resources can be reduced by 67% and at the same time the indicators of scientific publication activity will not decrease. Conclusions about relative efficiency are better made by calculations of pure technical efficiency (*PTE*) because both the efficiency of the use of resources and the efficiency of the scale of activity are considered. The following HEIs had the highest value of pure technical efficiency (*PTE*): Oles Honchar Dnipro National University, National Technical University "Kharkiv Polytechnic Institute", Chernihiv Polytechnic National University, Odesa State Agrarian University, Odesa State Ecological University, I.I. Mechnykov Odesa National University, Cherkasy State Technological University, Yuriy Fedkovych Chernivtsi National University. The minimum value of pure technical efficiency (*PTE*) corresponded to the National University of Life and Environmental Sciences of Ukraine and was $PTE=0.35$. The reasons for the inefficient operation of the mentioned HEIs are the irrational use of resources and the small scale of activity, it works in the zone of Increasing Return to Scale (*IRS*).

The maximum technical efficiency (*TE*) of scientific publication activity was achieved by the seven HEIs under study, based on the data presented in Table 4. The percentage of efficient ones was 18%. Thus, 82% of HEIs use resources irrationally. The maximum pure technical efficiency (*PTE*) of scientific publication activity was achieved by eight HEIs under study. The percentage of efficient ones was 21%, i.e., 79% of HEIs use resources irrationally and have an unbalanced scale of activity. Only seven HEIs operate in the zone of the most productive scale (*CRS*). The percentage of efficient activities in terms of scale is 18%. In other words, 82% of HEIs can increase efficiency by changing the scale of their activities. The average scale efficiency is $SE=0.85$. In the zone with an increasing return to scale (*IRS*) there are twenty-eight HEIs. The size of the activity of these HEIs is too small from the optimal one. The scale of activity is too large for three HEIs. These HEIs operate in a zone with a decreasing return to scale (*DRS*).

According to the results of the calculations presented in Table 5, the first place in the rating of technical efficiency was shared by the following HEIs: Oles Honchar Dnipro National University, Chernihiv Polytechnic National University, Odesa State Agrarian University, Odesa State Ecological University, I.I. Mechnykov Odesa National University, Cherkasy State Technological University, Yuriy Fedkovych Chernivtsi National University. These universities efficiently use educational resources. The first place in the rating of pure technical efficiency was shared by the following HEIs: Oles Honchar Dnipro National University, National Technical University "Kharkiv Polytechnic Institute", Chernihiv Polytechnic National University, Odesa State Agrarian University,

Odesa State Ecological University, I.I. Mechnykov Odesa National University, Cherkasy State Technological University, Yuriy Fedkovych Chernivtsi National University. These HEIs are efficient in terms of the use of educational resources and the scale of their activities. The rating values displayed in Table 5 can be used as a benchmarking tool, by which reference objects are determined, and comparative analysis is carried out to improve the efficiency of activities.

► Conclusions

Different authors use different specifications of DEA models to measure the effectiveness of educational and scientific activities. The variety of models used is primarily determined by different combinations of input and output data. In the conducted study, the models of the DEA method were selected, input and output data were presented for the evaluation and analysis of the efficiency of the scientific publication activity of agrarian higher education institutions of Ukraine, and the identification of the cause of inefficiency.

According to the study results, eight agrarian HEIs in Ukraine have the maximum pure technical efficiency of scientific publication activities. These HEIs are efficient in terms of the use of the educational resources, and the scale of their activities. 18% of the HEIs under study efficiently use the educational resources and 18% have an optimal scale of activity. The average technical efficiency is 0.6, the average pure technical efficiency is 0.7, and the average scale efficiency is 0.85, which is quite high. Investigated HEIs that are inefficient according to the DEA method can improve efficiency indicators by optimizing resource indicators and changing the

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scale of operations. One of the advantages of using the non-parametric DEA method is the ability to determine the optimal values of input and output variables, which allow the business entity to achieve maximum efficiency. The task of further research is to determine, using the DEA method, the main resource indicators of agrarian HEIs, which will allow inefficient HEIs to become as efficient as possible. Notably, relative efficiency is calculated using the DEA method. Therefore, HEIs that rank first in the compiled rating can also increase efficiency. For this, both the best universities in the world and countries can be selected as reference objects, but with modified indicators. The choice of reference HEIs should be made by experts. Improving the efficiency of agrarian HEIs, which have maximum efficiency, is also the task of further research.

The results of the ranking of agrarian HEIs of Ukraine according to the effectiveness of scientific publication activities reflect the results of the activity of a certain HEI, are a tool for decision-making by stakeholders, are the HEI's tool for marketing, external audit, self-analysis, and benchmarking.

The study results can be used to rank agrarian HEIs according to the efficiency of scientific publication activities, to determine the reasons for their inefficient work, and to provide reasonable recommendations for increasing efficiency to the maximum level.

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► Conflict of Interest

None.

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Оцінка ефективності аграрних закладів вищої освіти України методом DEA

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► **Анотація.** Актуальність дослідження зумовлена необхідністю удосконалення процесу оцінки ефективності наукової і освітньої діяльності закладів вищої освіти країни та визначення причин неефективності. Мета статті – вдосконалити процес оцінки ефективності науково-публіцистичної діяльності аграрних закладів вищої освіти України методом Data Envelopment Analysis. Дослідження здійснювалось за загальним евристичним методом, застосовувались математико-статистичні методи обробки та аналізу вхідних та вихідних даних, комп'ютерні методи для реалізації задач дослідження та абстрактно-логічні для визначення ступеню актуальності, формулювання висновків. У дослідженні обґрунтовано доцільність застосування непараметричного методу Data Envelopment Analysis для оцінки ефективності наукової і освітньої діяльності закладів вищої освіти, а також доцільність використання Voluntary Retirement Services та Compulsory Retirement Service моделей, що орієнтовані на вхід для оцінки технічної, чистої технічної, масштабної ефективності науково-публіцистичної діяльності. На основі статистичної інформації за 2020-2021 роки методом Data Envelopment Analysis здійснено оцінку технічної, чистої технічної, масштабної ефективності науково-публіцистичної діяльності 38 аграрних закладів вищої освіти України. За результатами розрахунків 18% досліджуваних закладів освіти мають максимальне значення технічної та масштабної ефективності. Середня технічна ефективність складає 0,6, середня чиста технічна ефективність – 0,7, середня масштабна ефективність – 0,85. Аналіз оцінених значень відносної ефективності дозволив виявити причини неефективності кожного досліджуваного закладу вищої освіти, серед яких неоптимальне використання освітніх ресурсів та незбалансований масштаб діяльності. За результатами дослідження складено рейтинг аграрних закладів вищої освіти України за ефективністю науково-публіцистичної діяльності, який може бути використаний як доповнення до традиційних рейтингів аналізу наукової та освітньої діяльності. Результати досліджень можуть бути використані для ранжування закладів вищої освіти за ефективністю, визначення причин їх неефективної діяльності

► **Ключові слова:** аграрні заклади вищої освіти; метод Data Envelopment Analysis; технічна ефективність; чиста технічна ефективність; масштабна ефективність; рейтинг