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Evaluation of the efficiency of agricultural higher education institutions of Ukraine and the dynamics of its change by data envelopment analysis

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► **Abstract.** Presently, the process of assessing the effectiveness of higher education institutions and analysing the dynamics of its change needs to be improved, which determines the relevance of this study. The purpose of this study was to improve the assessment of the efficiency of agricultural higher education institutions of Ukraine in the scientific and journalistic context, as well as to investigate the changes in dynamics using the non-parametric method of assessing the relative efficiency of data envelopment analysis. The study used methods of statistical processing and data analysis, linear programming, computer computing to solve research problems, and logical and analytical methods to determine the purpose of the study, the means of achieving it, substantiate the findings of the study, and formulate conclusions. To evaluate the effectiveness of scientific and publishing activities of these higher education institutions, the input-oriented model of variable returns to scale of the data envelopment analysis method was applied. Using statistical data for 2020-2022, the net technical efficiency of scientific and publishing activities of 37 agricultural higher education institutions of Ukraine was assessed. Based on the results of the assessment, a rating of agricultural higher education institutions in Ukraine was compiled. It was found that in 2021 and 2022, 27% of the surveyed higher education institutions were 100% effective. The average net technical efficiency in 2021 and 2022 was 0.91. In 2021-2022, 27% of agricultural higher education institutions increased the efficiency of scientific and publishing activities, 59% did not change, and 14% decreased. On average, there was a 1% increase in the use of educational resources in the field of agricultural higher education. Thus, the scientific and publication activities of agricultural higher education institutions during the study period are progressive. The findings of this study can be used for a reasonable ranking of higher education institutions according to the efficiency of scientific and publishing activities, analysis of the dynamics of changes in efficiency

► **Keywords:** higher education; scientific and publishing activity; non-parametric method of relative efficiency assessment; variable returns to scale model; net technical efficiency; rating; Malmquist index

► Introduction

Agrarian universities are business entities engaged in the development of the innovative potential of the agro-industrial complex (AIC), namely training of AIC specialists, provision of information, consulting and expert services, scientific and theoretical, scientific and applied research, making discoveries and inventions in the agricultural sector. Improving the efficiency of higher education institutions (HEIs) with an agricultural focus contributes to the innovative development of the agro-industrial complex. Therefore, it is relevant to develop methods for objective assessment of the level of efficiency of agricultural

universities, identify opportunities for improving efficiency, and analyse trends in the development of agricultural higher education.

Currently, to evaluate and analyse the efficiency of any business entity (including educational institutions), countries widely use a non-parametric method of assessing relative efficiency – data envelopment analysis (DEA). According to the ranking of countries by the number of users (User Count) who have purchased the software from the Data Envelopment Analysis Online Software hosting (Data Envelopment Analysis, n.d.), the United States

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ranks first (80,600 User Count), India is second (1,600 User Count), followed by Iran, the Islamic Republics (1,436 User Count), and others. The User Count of Ukraine is 32, which indicates that the practical application of the DEA method in Ukraine is not widespread. T. Pham Van *et al.* (2022) conducted a bibliometric analysis of 169 Scopus publications from 1988 to 2021 on the use of data envelopment analysis to assess performance in higher education. The following countries were identified as having the greatest influence on research on this topic: Italy, China, Spain, the United States, and the United Kingdom. Consequently, theoretical research on this topic is not widespread in Ukraine. The DEA method assesses the relative efficiency of converting input factors (resources) into output (performance results) for decision-making units (DMU). Ya. Dolhikh (2020) indicates the advantages of using the DEA method to assess the relative efficiency of similar DMUs, among which are the possibility of simultaneously analysing the impact of input factors on output factors without first determining their functional dependence and identifying the causes of inefficiency.

Among the scientific papers on the application of the data envelopment analysis method to assess the effectiveness of higher education institutions for 2020-2023, it is worth mentioning the study by K. Stefanova & N. Velichkov (2020), which uses the DEA method to investigate the cost-effectiveness of higher education in some EU member states. S. El Gibari *et al.* (2022) proposed a methodology for assessing the effectiveness of Spanish universities based on a combination of a multi-criteria benchmarking scheme to form consolidated performance indicators and the DEA method. G.V. Olariu & S. Brad (2022) assessed the relative effectiveness of 38 study programmes at a Romanian public university using CRS-, VRS-output-oriented DEA models for 2016-2019. R. Puertas *et al.* (2023) used the DEA method to assess the effectiveness of environmental policies of universities in Italy and Spain during 2018-2022. The study found an increase in its efficiency due to the introduction of innovative environmental measures. X. Zhao *et al.* (2023), using the BCC (or VRS) model of the DEA method, assessed the effectiveness of scientific and technological innovation (STI) of Chinese universities in 31 provinces for 2011-2020 and analysed the dynamics of its change. Based on the results obtained, proposals were made to improve the efficiency of STI universities through a scientific innovation alliance, and a mechanism for evaluating and managing innovations was developed. Z. Liu *et al.* (2023) used the DEA BCC model and the Malmquist index to analyse the performance of 34 Chinese universities for 2017-2021. It was found that the use of massive open online courses (MOOCs) contributes to efficiency. Among the scientific studies conducted in Ukraine, it is worth noting the study by O. Hryhorash *et al.* (2022), which uses the DEA method to assess the efficiency of higher education expenditures by students and the state in OECD countries and Ukraine and compares the efficiency of these expenditures. I. Lesik *et al.* (2022) used the data envelopment analysis method to assess the effectiveness of the management of the higher education system in 24 regions of Ukraine. The analysis of these studies revealed a substantial lack of theoretical and practical research on the evaluation of

the effectiveness of Ukrainian HEIs using the DEA method. The purpose of this study was to assess the effectiveness of scientific and publishing activities of agricultural HEIs, rank them by efficiency and analyse the dynamics of changes in efficiency.

► Materials and Methods

The study proposes to evaluate the effectiveness of scientific and publishing activities of agricultural HEIs using the DEA method. The essence of the DEA methodology is that DMU_k ($k = \overline{1; K}$), are studied that have a set of inputs (resources) given by a non-zero vector of input variables $X_k = (x_{k1}, x_{k2}, \dots, x_{km})$ and outputs (results) given by a non-zero vector of output variables $Y_k = (y_{k1}, y_{k2}, \dots, y_{kn})$. The DMU_0 activity under analysis is considered to be 100% technically efficient if it achieves the specified result with minimal resource consumption. For this condition, efficiency is assessed using the input-oriented DEA model, which minimises input variables with fixed outputs. The input-oriented orientation will allow to provide recommendations for achieving maximum results of scientific and publishing activities through resource optimisation, which is appropriate if the results of scientific and publishing activities are determined by the workload of academic staff (AS) and resource savings are required. The use of the input-oriented model provides more opportunities to monitor inputs and adjust them. DEA models are divided into constant returns to scale (CRS) and variable returns to scale (VRS) models. The efficiency calculated using the VRS model factors in the disproportionate change in performance due to changes in the amount of resources spent. The increase in the number of AS and funding of scientific activities does not lead to a proportional increase in scientific publications and their quality indicators. Technical efficiency is assessed using the VRS input-oriented model by solving a linear programming problem (Banker *et al.*, 1984):

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

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

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

where E is the input net technical efficiency; λ_k is the unknown coefficients; K is the number of DMU_k ; X_0, Y_0 are the vectors of input and output DMU_0 variables under analysis.

By solving the linear programming problem (1)-(3), the coefficients of the input and output variables are determined so that the calculated value of DMU_0 efficiency belongs to the interval $[0;1]$ and takes the highest possible value. DMUs with an efficiency equal to one are the most efficient and are called "reference" DMUs. The benchmark DMUs form a so-called efficiency frontier in the space of input-output variables.

A correct solution to the problem (1)-(3) is possible if the following non-degeneracy condition is met (Cooper *et al.*, 2006):

$$K \geq \max\{m \times n; 3(n + m)\}, \quad (4)$$

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

The analysis of the change in efficiency determined according to the DEA method should factor in the specific feature of the method, according to which the change in efficiency can be caused by both changes in the input and output parameters of DMU_0 and changes in the reference DMUs. The analysis of the change in the efficiency of DMU_k $k = (\overline{1}; \overline{K})$ in the current period compared to the previous one is carried out using the Malmquist index (Cooper *et al.*, 2007):

$$Mind = TCng \cdot \frac{E_1^1}{E_0^0}, \quad (5)$$

where $TCng = \sqrt{\frac{E_1^0}{E_1^1} \cdot \frac{E_0^0}{E_0^1}}$ is the technical shift of the efficiency frontier; E_0^0 is the efficiency of DMU_0 analysed in the period T_0 ; E_1^1 is the efficiency of DMU_0 in the period T_1 ; E_0^1 is the efficiency of DMU_0 with indicators in the period T_0 relative to the frontier of efficient DMUs in the period T_1 ; E_1^0 is the efficiency of DMU_0 with indicators in the period T_1 relative to the frontier of efficient DMUs in the period T_0 .

If $Mind = 1$, the efficiency of the DMU_0 under study has not changed, if $Mind > 1$, it has increased, if $Mind < 1$, it has decreased. According to the formula (5), the Malmquist index is formed by multipliers that characterise the change in the technical (innovation) process ($TCng$) and the change in efficiency (E_1^1/E_0^0). The DEA models were

calculated using the developed VBA program for Microsoft Excel.

The statistical database of input data values that characterise the scientific and publishing activities of agricultural HEIs, namely the number of AS, the amount of funding for the HEIs under study, the amount of their funding depending on performance indicators, indicators of large-scale scientific activities of HEIs in 2021, 2022, was formed according to the Distribution of funds from the state budget between higher education institutions (n.d.). The statistical database of output data values, namely the number of publications in Scopus of the AS, the number of citations of the AS, the Hirsch index of the AS of the HEIs under study in 2021, 2022, was formed based on the information of university rankings according to Scopus indicators in 2021, 2022 (Scopus ranking of universities in 2021, 2021; Scopus ranking of universities in 2022, 2022).

Agricultural HEIs of Ukraine, namely universities, academies, institutes with an agricultural focus in research and education, were selected as DMU_k ($k = \overline{1}; \overline{K}$), to be assessed by the DEA method. Among these HEIs, 37 were selected, which are engaged in educational and research activities in the following areas: "Agricultural Sciences and Food", "Production and Technology", and "Natural Sciences". Table 1 shows a sample of DMU_k ($k = \overline{1}; \overline{37}$) – 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 Ecological University
2	Vinnitsia National Agrarian University	21	I.I. Mechnykov Odesa National University
3	Uzhhorod National University	22	Podillia State University
4	Dnipro State Agrarian and Economic University	23	Polissia National University
5	Oles Honchar Dnipro National University	24	Poltava State Agrarian University
6	Zaporizhzhia National University	25	Vasyl Stefanyk Precarpathian National University
7	West Ukrainian National University	26	Sumy National Agrarian University
8	Lutsk National Technical University	27	Lesya Ukrainka Volyn National University (Lesya Ukrainka Eastern European National University)
9	Stepan Gzhytskyi National University of Veterinary Medicine and Biotechnologies of Lviv	28	Volodymyr Dahl East Ukrainian National University
10	Lviv National Environmental University (Lviv National Agrarian University)	29	Dmytro Motornyi Tavria State Agrotechnological University
11	Bogdan Khmelnytsky Melitopol State Pedagogical University	30	Ternopil Ivan Puluj National Technical University
12	Mykolaiv National Agrarian University	31	Uman National University of Horticulture
13	Ukrainian National Forestry University	32	O.M. Beketov National University of Urban Economy in Kharkiv
14	National Technical University "Kharkiv Polytechnic Institute"	33	Kherson State Agrarian and Economic University
15	Chernihiv Polytechnic National University	34	Khmelnytskyi National University
16	National University of Life and Environmental Sciences of Ukraine	35	Central Ukrainian National Technical University
17	National University of Water and Environmental Engineering	36	Cherkasy State Technological University
18	National University of Food Technologies	37	Yuriy Fedkovych Chernivtsi National University
19	Odesa State Agrarian University		

Source: Distribution of funds from the state budget between higher education institutions (n.d.)

The object of the study is the scientific and journalistic activity of agricultural universities in Ukraine. The composition of the factors of the VRS-input-oriented model was formed considering the specific features of the research object and the condition of non-degeneracy (4). The vector of input variables of the VRS-input-oriented model is formed by the following factors: 1) x_{1k} the number of AS, people; 2) x_{2k} the amount of funding for higher education institutions, UAH; 3) x_{3k} the amount of funding for higher education institutions depending on performance indicators, UAH; 4) x_{4k} the indicator of large-scale activity; 5) x_{5k} the indicator of scientific activity. The vector of output variables of the input-oriented VRS model is formed by the following factors: 1) y_{1k} is the

number of publications in Scopus by HEI's AS, pcs; 2) y_{2k} is the number of citations of HEI's AS, pcs; 3) y_{3k} is the Hirsch index of the HEI's AS. The selected input variables reflect the educational resources of the HEI, and the output variables are the results of scientific and publishing activities.

► Results

Results of the net technical efficiency assessment, analysis of the dynamics of its change. The values of the input variables for the construction of VRS models that assess the net technical efficiency of the research and publishing activities of the HEIs under study in 2021 and 2022 are presented in Table 2.

Table 2. Input data for building VRS models

No. DMU	For VRS 2021 ¹ models					For VRS 2022 ² models				
	AS, people	Financing of HEIs in 2020, UAH		Performance indicators		AS, people	Financing of HEIs in 2021, UAH		Performance indicators	
		Except for: ³	depending on performance indicators	large-scale	scientific		Except for: ³	depending on performance indicators	large-scale	scientific
1	376	87,320,968	5,004	1	1.1	376	103,366,688	14,258,913	1	1.1
2	316	69,723,256	13,456	1	1.1	327	76,474,697	8,763,805	1	1.1
3	1,275	203,580,480	1,485	1.2	1.1	1,285	242,022,316	33,139,287	1.2	1.1
4	343	66,804,992	271	1	1.3	327	88,047,177	13,570,066	1	1.3
5	871	244,274,352	9,906	1.2	1.2	826	238,619,619	25,009,747	1.2	1.2
6	710	128,402,216	2,112	1.2	1.1	665	145,644,765	17,361,578	1.2	1.2
7	686	114,421,632	1,043	1.2	1.1	686	129,709,915	14,559,395	1.2	1.1
8	413	106,160,400	2,211	1.2	1.3	413	136,452,343	24,340,299	1.2	1.3
9	330	84,610,096	6,356	1	1	330	105,460,174	11,458,896	1	1
10	320	80,065,528	518	1	1.1	290	98,732,284	8,931,183	1	1.1
11	278	62,646,868	2,194	1	1.1	278	76,274,031	7,420,337	1	1.1
12	352	80,888,976	5,831	1	1.4	352	107,920,540	12,844,898	1	1.4
13	349	80,075,856	15,337	1	1.2	314	94,061,749	7,982,530	1	1.2
14	1,387	368,192,064	11,321	1.4	1.3	1,387	441,909,986	65,334,853	1.4	1.4
15	311	101,270,840	4,206	1	1.4	260	119,943,862	14,493,104	1	1.4
16	1,270	453,143,712	12,579	1.4	1.4	1,210	532,128,935	70,201,158	1.4	1.4
17	589	135,840,528	8,055	1.2	1.2	549	169,684,683	25,892,383	1.2	1.3
18	608	170,255,792	4,003	1.2	1.1	577	180,078,202	20,070,877	1.2	1.1
19	141	27,885,960	1,432	0.8	1	141	31,496,643	2,884,867	0.8	1
20	179	47,197,424	963	0.8	1.2	168	43,324,650	2,638,414	0.8	1.2
21	759	113,510,200	2,096	1	1.2	759	128,828,526	13,534,966	1	1.3
22	213	55,024,400	7,170	1	1.3	199	60,050,078	7,080,327	1	1.3
23	356	69,505,344	17,623	1	1	356	87,687,366	11,843,556	1	1
24	325	68,667,240	1,909	1	1.1	325	91,467,533	12,418,680	1	1.1
25	893	125,292,944	4,467	1.2	1.1	876	154,785,175	20,665,030	1.2	1.1
26	431	116,555,880	10,042	1.2	1.2	385	149,600,957	25,130,460	1.2	1.3
27	741	147,902,336	7,355	1.2	1.1	722	181,148,090	25,703,717	1.2	1.2
28	379	124,084,840	6,683	1	1	371	128,988,330	12,343,448	1	1.1
29	291	81,642,504	996	1	1.2	292	100,200,652	12,224,238	1	1.2
30	408	82,569,280	3,174	1	1.2	401	94,720,593	12,697,461	1	1.2
31	320	74,766,088	2,108	1	1.2	295	96,850,754	12,687,970	1	1.1
32	499	107,834,272	1,407	1	1.4	499	127,641,942	16,700,369	1	1.3
33	216	46,650,324	11,081	1	1.1	216	59,899,945	7,169,768	1	1.1

Table 2, Continued

No. DMU	For VRS 2021 ¹ models					For VRS 2022 ² models				
	AS, people	Financing of HEIs in 2020, UAH		Performance indicators		AS, people	Financing of HEIs in 2021, UAH		Performance indicators	
		Except for: ³	depending on performance indicators	large-scale	scientific		Except for: ³	depending on performance indicators	large-scale	scientific
34	544	101,756,008	2,072	1	1.1	544	119,018,448	13,707,116	1	1.1
35	323	73,545,648	2,234	1	1.1	311	88,162,710	10,091,433	1	1.1
36	369	72,333,984	341	1	1	345	74,946,847	8,034,883	1	1
37	1,101	176,465,248	193	1.2	1.1	1,035	207,844,329	30,050,709	1.2	1.1

Note: ¹ DEA models assessing the effectiveness of the research and publishing activities of the DMUs studied in 2021; ² DEA models assessing the effectiveness of the research and publishing activities of the DMUs studied in 2022; ³ 1) social and other payments; 2) reserve

Source: Distribution of funds from the state budget between higher education institutions (n.d.)

The values of the output variables for the construction of VRS models that evaluate the effectiveness of scientific and publishing activities of the HEIs under study in 2021, 2022 are presented in Table 3.

Table 3. Input data for building VRS models

No. DMU	For VRS-2021 models			For VRS-2022 models		
	Number of Scopus publications by HEI's AS in 2021, pcs.	Number of citations of HEI's AS in 2021, pcs.	Hirsch Index of HEI's AS in 2021	Number of Scopus publications by HEI's AS in 2022, pcs.	Number of citations of HEI's AS in 2022, pcs.	Hirsch Index of HEI's AS in 2022
1	173	590	13	235	235	14
2	206	515	10	289	951	13
3	2,673	14,444	43	3,078	16,922	45
4	280	765	11	377	1,104	14
5	4,262	18,456	46	4,698	21,159	49
6	972	2,374	21	1,137	3,034	22
7	961	2,765	21	1,161	3,812	23
8	561	1,058	13	650	1,996	15
9	286	1,970	22	352	2,376	23
10	233	722	9	315	1,141	13
11	174	536	11	250	1,030	15
12	205	517	12	315	1,008	15
13	363	3,292	26	425	4,416	28
14	4,890	19,915	48	5,532	24,238	53
15	467	1,825	19	541	2,453	22
16	1,730	6,645	32	2,329	9,770	38
17	722	2,402	19	909	3,714	25
18	717	3,243	25	819	4,102	26
19	34	64	6	58	121	6
20	296	1,631	17	351	2,101	18
21	3,916	25,987	67	4,191	29,503	71
22	101	143	6	142	363	9
23	244	546	11	576	1,121	13
24	243	418	9	331	776	13
25	1,152	11,944	47	1,404	15,648	54
26	463	1,932	20	686	2,901	24
27	975	7,082	32	1,139	8,462	33
28	943	3,498	21	1,172	4,568	25
29	281	668	12	402	1,158	16

Table 3, Continued

No. DMU	For VRS-2021 models			For VRS-2022 models		
	Number of Scopus publications by HEI's AS in 2021, pcs.	Number of citations of HEI's AS in 2021, pcs.	Hirsch Index of HEI's AS in 2021	Number of Scopus publications by HEI's AS in 2022, pcs.	Number of citations of HEI's AS in 2022, pcs.	Hirsch Index of HEI's AS in 2022
30	910	2,832	17	1,052	3,923	22
31	211	306	9	278	429	10
32	597	1,440	17	765	2,224	20
33	123	349	10	182	609	14
34	684	2,812	19	811	3,752	23
35	261	606	10	299	839	13
36	294	1,093	20	336	1,322	20
37	3,995	20,227	64	4,332	23,307	66

Source: Scopus ranking of universities in 2021 (2021); Scopus ranking of universities in 2022 (2022)

The formation of the database of statistical values of input and output variables was carried out considering the time lag – the results of scientific and publishing activities are possible at least 1 year after the action of the input factors. Next, the study checked if the non-degeneracy condition (4) is met: $37 \geq \max\{5 \times 3; 3(5+3)\}$; $37 \geq 24$. Thus,

condition (4) is satisfied.

Results of the net technical efficiency assessment. Table 4 contains the results of calculations of the net technical efficiency of scientific and publishing activities of Ukrainian agricultural HEIs in 2021 (E_0^0) and 2022 (E_1^1), and the rankings of agricultural HEIs based on the assessed efficiency.

Table 4. Results of calculations of the net technical efficiency of scientific and publishing activities of agricultural HEIs of Ukraine in 2021, 2022 and ratings of agricultural HEIs of Ukraine according to the estimated efficiency values

No. DMU	2021	2022	DMU ranking, 2021			DMU ranking, 2022		
	E_0^0	E_1^1	No. DMU	E_0^0	Rank	No. DMU	E_1^1	Rank
1	0.9091	0.9091	5	1	1	5	1	1
2	0.9091	0.9095	9	1	1	9	1	1
3	0.9686	0.9723	14	1	1	14	1	1
4	0.8098	0.8179	19	1	1	19	1	1
5	1.0000	1.0000	20	1	1	20	1	1
6	0.9124	0.8471	21	1	1	21	1	1
7	0.9164	0.9257	23	1	1	23	1	1
8	0.7698	0.7756	28	1	1	25	1	1
9	1.0000	1.0000	36	1	1	36	1	1
10	0.9091	0.9100	37	1	1	37	1	1
11	0.9091	0.9112	25	0.9810	2	13	0.9730	2
12	0.8007	0.8056	3	0.9686	3	3	0.9723	3
13	0.9260	0.9730	27	0.9316	4	28	0.9614	4
14	1.0000	1.0000	13	0.9260	5	33	0.9510	5
15	0.8196	0.8505	34	0.9210	6	34	0.9299	6
16	0.7364	0.7502	7	0.9164	7	7	0.9257	7
17	0.8333	0.7886	18	0.9161	8	18	0.9189	8
18	0.9161	0.9189	6	0.9124	9	11	0.9112	9
19	1.0000	1.0000	33	0.9093	10	24	0.9103	10
20	1.0000	1.0000	1	0.9091	11	10	0.9100	11
21	1.0000	1.0000	2	0.9091	11	35	0.9097	12
22	0.8007	0.8019	10	0.9091	11	2	0.9095	13
23	1.0000	1.0000	11	0.9091	11	1	0.9091	14
24	0.9091	0.9103	24	0.9091	11	31	0.9091	14
25	0.9810	1.0000	35	0.9091	11	30	0.8763	15
26	0.8333	0.8161	30	0.8630	12	27	0.8589	16
27	0.9316	0.8589	29	0.8418	13	29	0.8580	17
28	1.0000	0.9614	31	0.8345	14	15	0.8505	18
29	0.8418	0.8580	17	0.8333	15	6	0.8471	19

Table 4, Continued

No. DMU	2021	2022	DMU ranking, 2021			DMU ranking, 2022		
	E_0^0	E_1^1	No. DMU	E_0^0	Rank	No. DMU	E_1^1	Rank
30	0.8630	0.8763	26	0.8333	15	32	0.8371	20
31	0.8345	0.9091	32	0.8204	16	4	0.8179	21
32	0.8204	0.8371	15	0.8196	17	26	0.8161	22
33	0.9093	0.9510	4	0.8099	18	12	0.8056	23
34	0.9210	0.9299	22	0.8007	19	22	0.8019	24
35	0.9091	0.9097	12	0.8007	20	17	0.7886	25
36	1.0000	1.0000	8	0.7698	21	8	0.7756	26
37	1.0000	1.0000	16	0.7364	22	16	0.7502	27

Source: calculated by the author of this study

According to the results of the calculations presented in Table 4, the following agricultural HEIs of Ukraine had the highest relative efficiency of scientific and publishing activities in 2021 and 2022: Oles Honchar Dnipro National University, S.Z. Gzhytskyi Lviv National University of Veterinary Medicine and Biotechnology, National Technical University "Kharkiv Polytechnic Institute", Odesa State Agrarian University, Odesa State Environmental University, I.I. Mechnykov Odesa National University, Polissia National University, Cherkasy State Technological University, Yuriy Fedkovych Chernivtsi National University.

In addition, in 2021, the maximum relative efficiency of scientific and journalistic activities was achieved by the Volodymyr Dahl East Ukrainian National University, and in 2022 – by the Vasyl Stefanyk Precarpathian National University. The minimum effectiveness of scientific and journalistic activities in 2021 and 2022 was achieved by the National University of Life and Environmental Sciences of Ukraine. The calculated value of the estimated efficiency of this HEI was 0.74 in 2021 and 0.75 in 2022. Table 5 shows a summary of the net technical efficiency assessment.

Table 5. Summary indicators of net technical efficiency

Indicators	E_0^0	E_1^1
Number of effective ones	10	10
Percentage of effective ones	27.03	27.03
Average efficiency	0.9081	0.9104

Source: calculated by the author of this study

According to the calculations presented in Table 5, in 2021 and 2022, the share of agricultural higher education institutions with the highest efficiency of scientific and publishing activities was 27%. Thus, 63% of the surveyed HEIs can improve their performance by reducing the

amount of resources used. The average relative net technical efficiency was 0.91. Table 6 shows the results of the net technical efficiency assessment for 2021 (E_0^0) and 2022 (E_1^1), indicators of efficiency change (E_1^1/E_0^0), technical progress ($TCng$), Malmquist index ($Mind$).

Table 6. Net technical efficiency of scientific and publishing activities of agricultural HEIs of Ukraine in 2021, 2022, indicators of its change for 2021-2022

No. DMU	E_0^0	E_1^1	E_1^1/E_0^0	$TCng$	$Mind$
1	0.9091	0.9091	1.0000	1.0000	1.0000
2	0.9091	0.9095	1.0004	1.0075	1.0079
3	0.9686	0.9723	1.0038	1.0177	1.0216
4	0.8098	0.8179	1.0100	1.0010	1.0110
5	1.0000	1.0000	1.0000	1.0000	1.0000
6	0.9124	0.8471	0.9284	1.0063	0.9343
7	0.9164	0.9257	1.0101	1.0108	1.0210
8	0.7698	0.7756	1.0075	0.9947	1.0022
9	1.0000	1.0000	1.0000	1.0000	1.0000
10	0.9091	0.9100	1.0010	1.0067	1.0077
11	0.9091	0.9112	1.0023	1.0278	1.0302
12	0.8007	0.8056	1.0061	1.0015	1.0076
13	0.9260	0.9730	1.0508	1.0183	1.0700
14	1.0000	1.0000	1.0000	1.0000	1.0000
15	0.8196	0.8505	1.0377	1.0361	1.0752

Table 6, Continued

No. DMU	E_0^0	E_1^1	E_1^1/E_0^0	<i>TCng</i>	<i>Mind</i>
16	0.7364	0.7502	1.0187	0.9998	1.0186
17	0.8333	0.7886	0.9464	0.9982	0.9447
18	0.9161	0.9189	1.0031	1.0044	1.0074
19	1.0000	1.0000	1.0000	1.0000	1.0000
20	1.0000	1.0000	1.0000	1.0000	1.0000
21	1.0000	1.0000	1.0000	1.0000	1.0000
22	0.8007	0.8019	1.0015	1.0010	1.0025
23	1.0000	1.0000	1.0000	1.0000	1.0000
24	0.9091	0.9103	1.0013	1.0000	1.0013
25	0.9810	1.0000	1.0194	0.9905	1.0096
26	0.8333	0.8161	0.9794	1.0046	0.9839
27	0.9316	0.8589	0.9220	1.0086	0.9299
28	1.0000	0.9614	0.9614	0.9988	0.9603
29	0.8418	0.8580	1.0192	0.9981	1.0173
30	0.8630	0.8763	1.0154	0.9971	1.0125
31	0.8345	0.9091	1.0894	0.9995	1.0889
32	0.8204	0.8371	1.0204	1.0014	1.0218
33	0.9093	0.9510	1.0459	1.0039	1.0499
34	0.9210	0.9299	1.0097	1.0062	1.0159
35	0.9091	0.9097	1.0007	1.0039	1.0045
36	1.0000	1.0000	1.0000	1.0000	1.0000
37	1.0000	1.0000	1.0000	1.0000	1.0000

Source: calculated by the author of this study

Thus, the following agricultural universities did not change their performance in 2021-2022: Bila Tserkva National Agrarian University, Oles Honchar Dnipro National University, Stepan Gzhytskyi National University of Veterinary Medicine and Biotechnologies of Lviv, National Technical University "Kharkiv Polytechnic Institute", Odessa State Agrarian University, Odessa State Environmental University, I.I. Mechnykov Odessa National University, Polissia National University, Cherkasy State Technological University, Yuriy Fedkovych Chernivtsi National University. The following agrarian HEIs have increased their efficiency: Vinnytsia National Agrarian University, Uzhhorod National University, Dnipro State Agrarian and Economic University, Western Ukrainian National University, Lutsk National Technical University, Lviv National University of Environmental Management, Bogdan Khmelnytsky Melitopol State Pedagogical University, Mykolaiv National Agrarian University, National Forestry University of Ukraine, National University "Chernihiv Polytechnic", National University of Life and Environmental Sciences of Ukraine, National University of Food Technologies, Podillia State University, Poltava State Agrarian University, Vasyl Stefanyk Precarpathian National University, Dmytro

Motorny Tavria State Agrotechnological University, Ternopil Ivan Puluj National Technical University, Uman National University of Horticulture, O.M. Beketov National University of Urban Economy in Kharkiv, Kherson State Agrarian and Economic University, Khmelnytskyi National University, Central Ukrainian National Technical University. The following higher education institutions decreased their efficiency: "Zaporizhzhia National University, National University of Water and Environmental Engineering, Sumy National Agrarian University, Lesya Ukrainka Volyn National University, and Volodymyr Dahl East Ukrainian National University.

The analysis of the values of the indicators of change in efficiency (E_1^1/E_0^0) and technical progress (*TCng*) presented in Table 6 allows concluding on the reasons for the change in efficiency. For instance, the decrease in the efficiency of scientific and publishing activities of the Sumy National Agrarian University by 1.61% (*Mind* = 0.9839) is conditioned by a decrease in the relative efficiency of the use of resources of the said university by 2.06% (E_1^1/E_0^0) = 0.9794) and a shift in the efficiency limit by 0.46% (*TCng* = 1.0046). Table 7 shows the indicators used to analyse the dynamics of changes in net technical efficiency in 2021-2022.

Table 7. Indicators of changes in net technical efficiency for 2021-2022

No.	Indicators	<i>TCng</i>	<i>Mind</i>
1.	Average value	1.004	1.01
2.	DMU share from <i>Mind</i> = 1, %		27
3.	DMU share from <i>Mind</i> > 1, %		59
4.	DMU share from <i>Mind</i> < 1, %		14

Source: calculated by the author of this study

Table 7 shows the calculated average value of the technical progress indicator $TCng = 1.004$, which indicates a 0.4% shift in the efficiency frontier. Thus, in 2021-2022, there has been a general progress in the scientific and publishing activities of agricultural universities. The average value of the Malmquist Index $Mind = 1.01$ calculated for 2021-2022 shows that, on average, the efficiency of using educational resources of the HEIs under study increased by 1%. Thus, to achieve the results of scientific and publishing activities in 2021, agrarian higher education institutions used 1% less educational resources in 2022. The share of agrarian higher education institutions whose effectiveness of scientific and publishing activities did not change in 2021-2022 is 27%, increased – 59%, decreased – 14%.

► Discussion

The study assessed the net technical efficiency of the scientific and publishing activities of agricultural universities in 2021 and 2022. The evaluation was based on five input factors (number of AS, total funding of HEIs and funding of HEIs depending on performance indicators, indicators of scale and scientific activity), and three output factors (number of publications in Scopus, number of citations, Hirsch index). The input factors characterise the resources required for the implementation of scientific and journalistic activities, and the output factors are the results of scientific and journalistic activities. Since the results of scientific and publishing activities do not change in direct proportion to the resources involved, the study rejected the hypothesis of constant returns to scale and applied the VRS model, which factors in variable returns. Since the results of scientific and publishing activities of AS of Ukrainian HEIs are regulated by the regulation on the standardisation of scientific work and managers of HEIs are interested in saving educational resources, the input-oriented orientation of the model was chosen.

I. Lesik *et al.* (2022) analyse the higher education system in the regions of Ukraine, and therefore the HEIs of the regions of Ukraine were chosen as DMUs. C. Wang *et al.* (2023), X. Zhao *et al.* (2023) chose universities in the provinces of China as DMUs. T. Qi *et al.* (2022) assess the effectiveness of research activities of different types of universities in China. The following types of universities have been selected as DMUs: Comprehensive University, Engineering University, Agriculture and Forestry University, Pharmaceutical University, Normal University, etc. In the current study, individual universities were selected as DMUs, which allows providing recommendations for improving the efficiency of higher education institutions.

Among the scientific papers on the application of the DEA method in education are those that investigate certain areas of activity of HEIs, namely, training, research, scientific and journalistic, reproduction of scientific personnel, etc. There is no set of standardised indicators that define the input and output parameters of any HEI activity, and therefore there is a wide variety of combinations of input and output factors in scientific articles. M. Sagarra *et al.* (2017) assessed the effectiveness of the implementation of the programme of modernisation of education in Mexican universities, namely its impact on the efficiency of educational activities and research, using

the DEA method. Based on the official statistics of 55 universities, 21 DEA models were built according to various performance criteria. M.B. Canto & L.B. López (2018) conducted a bibliographic analysis of research on the application of the DEA method in higher education to determine the input and output factors used to assess the effectiveness of HEIs. From the bibliographic review, it is concluded that most of the input and output parameters reflect the university's scientific activities. Next, the study analysed the articles investigating the effectiveness of the scientific direction of the HEI. J. Jiang *et al.* (2020) assessed the research efficiency of 105 universities in China and found that the research efficiency of the selected universities differs by their types. T. Qi *et al.* (2022), X. Zhao *et al.* (2023) also noted that research activity depends on the type of university. T. Qi *et al.* (2022) used the DEA method to investigate the static and dynamic trends in the efficiency of research of different types of universities in China for 2016-2020. According to the comparative analysis of the study, the highest level of efficiency is in general education, science and technology, and medical universities, followed by pedagogical universities, agriculture, and forestry. To ensure the correctness of the ranking of higher education institutions by the effectiveness of scientific and publishing activities, the current study selected higher education institutions of the same type. To assess the effectiveness of research activities of Chinese provincial universities, C. Wang *et al.* (2023) selected input and output factors based on the analysis of the percentage of factors used in research papers and a survey of experts on resources and results of research activities. As a result, four input and output factors were selected. The following factors were selected as input factors: the number of academic and research staff, full-time equivalent for R&D (persons/year), funds allocated for research per year, and the total number of research topics. The following were chosen as the initial indicators: the number of monographs, articles, income from technology transfer, and awards for scientific achievements. The qualitative description of some input and output parameters of C. Wang *et al.* (2023) is analogous in its qualitative description of the selected parameters to the present study. Consideration of the percentage of factors used in scientific papers is vital when selecting input and output factors, but in the present study, the main criterion for selecting factors was to obtain data from open sources, which contributes to the transparency of the study and also makes it possible to remotely assess effectiveness. In the present study, it is vital to consider the non-degeneracy condition (4) when forming an array of input and output factors. Failure to factor this condition in can lead to distorted results. T. Qi *et al.* (2022), C. Wang *et al.* (2023) estimated the net technical efficiency using the VRS-input-oriented model, as in the present study. Furthermore, C. Wang *et al.* (2023) assessed technical efficiency using the CRS-input-oriented model, which was used to assess scale efficiency. The assessment of large-scale efficiency and its analysis are planned to be carried out in the following studies. S.M. Chao & M.J. Chen (2023) used the CRS-, VRS-output-oriented DEA models to assess the research efficiency of 40 university departments to measure the effectiveness of research in terms of outputs.

The studies by T. Agasisti *et al.* (2021), T. Qi *et al.* (2022), X. Zhao *et al.* (2023), as well as in the current study, analysed the dynamics of changes in the estimated efficiency using the Malmquist index.

The analysis of scientific studies on the application of the DEA method in higher education has found that the studies differ in the selected DMUs of higher education and educational indicators that characterise the area of their activities. Generally, the issues of using the DEA method to assess the effectiveness of higher education institutions in Ukraine and analyse the dynamics of its change have not been fully studied.

► Conclusions

To analyse the effectiveness of scientific and journalistic activities of agricultural higher education institutions of Ukraine, the conducted study chose the DEA method model – input-oriented VRS, as well as input and output factors that factor in the specifics of scientific and publishing activities. According to the study, in 2021 and 2022, ten out of 37 agricultural HEIs in Ukraine had the highest net technical efficiency of scientific and publishing activities. These HEIs are efficient in the use of educational resources. The average net technical efficiency of Ukrainian agricultural universities in 2021 and 2022 was 0.91, which means that there is potential for increasing efficiency – 9% of the educational resources used can be reduced without reducing the results of scientific and publishing activities. Based on the assessed performance values, a rating of agricultural HEIs for 2021 and 2022 was compiled, which can be recommended as a supplement to existing evaluation ratings. Inefficient HEIs can improve their performance by optimising resources.

During 2021-2022, an average increase in the efficiency of scientific and publishing activities of Ukrainian

agricultural universities by 1% was observed. Thus, the process of scientific and journalistic activity of agricultural universities in Ukraine is progressive. The finding of this study can be used to rank agricultural higher education institutions by the efficiency of scientific and publishing activities, to substantiate recommendations for improving efficiency to the maximum level. The analysis of the efficiency estimated according to the DEA method in the dynamics allows investigating the shift of the efficiency limit over time and conclude on the development of scientific and publishing activities of HEIs: progressive or regressive.

Further research is planned to determine the values of resource indicators of agricultural higher education institutions using the DEA method, which will allow inefficient higher education institutions to become 100% efficient. Higher education institutions that rank first can also improve their efficiency. For this, it is necessary to evaluate a sample using the DEA method, which includes DMUs that form the efficiency frontier and new reference DMUs, which can be either the best universities in the world or the country, but with modified indicators. Increasing the efficiency of agricultural HEIs that have 100% efficiency according to the calculations is also a future objective of the research.

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► Conflict of Interest

The author of this study declares no conflict of interest.

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Оцінка ефективності аграрних закладів вищої освіти України та динаміки її зміни методом data envelopment analysis

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► **Анотація.** На теперішній час потребує удосконалення процес оцінки ефективності діяльності закладів вищої освіти та аналізу динаміки її зміни, що обумовлює актуальність дослідження. Мета статті полягала у вдосконаленні процесу оцінки ефективності діяльності аграрних вищих навчальних закладів України в науково-публіцистичному контексті, а також у вивченні змін динаміки за допомогою непараметричного методу оцінки відносної ефективності data envelopment analysis. В дослідженні застосовувались методи статистичної обробки та аналізу даних, лінійного програмування, комп'ютерних обчислень для розв'язання задач дослідження та логіко-аналітичні методи для визначення мети дослідження, засобів її досягнення, обґрунтування результатів дослідження, формулювання висновків. Для оцінки ефективності науково-публіцистичної діяльності зазначених закладів вищої освіти застосовано input-oriented модель Variable returns to scale методу data envelopment analysis. Використовуючи статистичні дані за 2020-2022 роки, здійснено оцінку чистої технічної ефективності науково-публіцистичної діяльності 37 аграрних закладів вищої освіти України. За результатами оцінки складено рейтинг аграрних закладів вищої освіти України. Встановлено, що у 2021 та 2022 році 27 % досліджуваних закладів вищої освіти були 100 % ефективними. Середня чиста технічна ефективність у 2021 та 2022 році складала 0,91. За період 2021-2022 роки 27 % аграрних закладів вищої освіти збільшили ефективність науково-публіцистичної діяльності, 59 % – не змінили, 14 % – зменшили. В середньому, зафіксовано підвищення на 1 % у рівні використання освітніх ресурсів у сфері аграрної вищої освіти. Отже, науково-публіцистична діяльність аграрних закладів вищої освіти за досліджуваний період є прогресивною. Результати проведених досліджень можуть бути використані для обґрунтованого ранжування закладів вищої освіти за ефективністю науково-публіцистичної діяльності, аналізу динаміки зміни ефективності

► **Ключові слова:** вища освіта; науково-публіцистична діяльність; непараметричний метод оцінки відносної ефективності; модель Variable returns to scale; чиста технічна ефективність; рейтинг; індекс Малмквіста