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Financial instruments for promoting resource conservation in the agricultural sector

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Abstract. The transformation of the agricultural sector towards sustainable development requires effective financial mechanisms to implement environmentally oriented technologies and management practices. The study aimed to analyse the efficiency and specific features of applying modern financial instruments to promote resource-saving practices in the agricultural sector and to develop recommendations for their optimal use. The methodology combined quantitative and qualitative analytical methods, using systemic, comparative, and statistical analysis of 4 efficiency indicators for financial instruments across 10 countries worldwide for the period 2020-2024. An Efficiency Composite Index (ECI) was developed based on five key components of resource efficiency using descriptive statistics, correlation, and multiple regression analysis. The study revealed that green loans (34.2% of total funding) and government subsidies (28.7%) were the dominant sources among eight types of financial instruments. Green loans demonstrated the highest efficiency in increasing resource efficiency (82.7 points) and the strongest correlation with reduced water consumption ($r = 0.89$), as shown by the example of the Danish company Arla Foods, which, after securing a €750 million green loan, reduced its water consumption by 23% and energy by 18%.Government subsidies proved most effective in improving environmental performance (79.8 points), as confirmed by the experience of the German organic farming support programme. Cluster analysis identified three groups of countries: "Innovation Leaders" with an average ECI of 86.7 points (Denmark, the Netherlands), "Stable Performers" with an ECI of 76.4 points (Germany, France, the USA, Canada), and "Developing Countries" with an ECI of 62.8 points (China, India, Ukraine, Poland). A significant synergistic effect was identified from the combined use of government subsidies and private investment (synergy coefficient of 1.34) and the universality of microfinance with the lowest variability between countries (12.7 points difference). Multiple regression analysis confirmed a statistically significant model ($R^2 = 0.78$), where the greatest impact on efficiency

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is exerted by the volume of green financing (β = 0.34) and the share of subsidies in Gross Domestic Product (β = 0.28). The practical significance of the study lies in the potential to apply the developed index to monitor and evaluate the effectiveness of national financial support programmes for resource efficiency

Keywords: green lending; environmental finance; resource efficiency; subsidy support; efficiency composite index; synergistic effects

INTRODUCTION

The agricultural sector faces unprecedented challenges: ensuring food security while simultaneously reducing negative environmental impacts and rationally using natural resources. The intensification of agricultural production has led to significant soil depletion, water pollution, and reduced biodiversity, underscoring the need to find effective mechanisms to promote resource-saving practices.

Global population growth, which is projected by the Organisation for Economic Co-operation and Development and the Food and Agriculture Organization of the United Nations (OECD-FAO, 2024) to reach 9.7 billion people by 2050, requires a 60-70% increase in food production, creating additional pressure on agroecosystems. Studies show that traditional approaches to financing the agricultural sector do not provide sufficient impetus for the implementation of environmentally oriented technologies and resource-saving practices. Traditional approaches to agricultural financing often fail to account for environmental externalities and the long-term consequences of intensive use of natural resources. According to FAO (2024) data, this results in short-term economic benefits being achieved at the expense of long-term degradation of natural capital. Consequently, there is a need to develop and implement innovative financial mechanisms to stimulate the adoption of resource-saving technologies and environmentally oriented management practices. The concept of green finance is becoming increasingly relevant in the context of the agricultural sector's transformation. According to Eurostat (2024) data, this concept involves the integration of environmental criteria into financial decision-making processes, which facilitates the direction of investment into projects that provide both economic and environmental benefits. Financial instruments that internalise environmental externalities and create economic incentives for implementing resource-saving practices are particularly important.

Financial instruments play a key role in the transition of the agricultural sector to a sustainable development model. O. Liubkina *et al.* (2019) emphasised the importance of financial mechanisms for promoting the innovative activity of enterprises, especially in the context of implementing resource-saving technologies. Y. Du & W. Wang (2023) investigated the role of green finance in agricultural development, establishing its positive impact on reducing environmental pollution. S. Liu & Y. Wang (2023) analysed the effect of green financial pilot zones on promoting environmental innovation, demonstrating the significant potential of financial instruments to transform the agricultural sector. M. Wang's (2023) research showed that green finance policy significantly increases the efficiency of green innovation in the manufacturing sector, with direct relevance to agricultural production. A. Mykhailov *et al.* (2021) substantiated the necessity of using investment instruments to manage innovative transformations of the agricultural sector in the context of globalisation. M. Abduh (2019) examined the role of Islamic social finance in achieving the Sustainable Development Goals, particularly in the field of food security and sustainable agriculture.

M. Al-Daihani *et al.* (2024) proposed an innovative model of Islamic crowdfunding for the agricultural sector, demonstrating the expansion of the range of available financial instruments. N. Boltianska *et al.* (2021) substantiated mechanisms for energy saving in the agricultural sector, which is an important component of resource-saving practices. Despite numerous studies, issues regarding the comprehensive use of various financial instruments to stimulate resource efficiency, the optimal combination of market and state financial support mechanisms, and the adaptation of international experience to the specifics of national agricultural systems remain insufficiently studied. Furthermore, mechanisms for evaluating the effectiveness of financial instruments in terms of achieving environmental goals, as well as their impact on the competitiveness of agricultural enterprises, require further investigation. An important aspect is also the research into the role of digital technologies in increasing the efficiency of financial instruments for promoting resource efficiency. The development of financial technologies opens new opportunities to create innovative financing mechanisms that can provide a more accurate assessment of environmental outcomes and automate financial support processes. Studies show particular relevance in studying the potential of blockchain technologies to ensure transparency and accountability in the use of funds directed towards resource-saving projects.

The aim of the study was to analyse the efficiency and specific features of applying modern financial support mechanisms to stimulate resource-saving practices in the agricultural sector and to develop differentiated recommendations for their optimal use for different groups of countries. To achieve this aim, the following research objectives were formulated: to evaluate the efficiency of different types of financial mechanisms for promoting resource efficiency based on statistical analysis using an Efficiency Composite Index (ECI); to substantiate scientific and practical recommendations for the comprehensive use of financial mechanisms to increase the resource efficiency of agricultural production in countries across different clusters of economic development.

MATERIALS AND METHODS

The methodological approach combined quantitative and qualitative analytical methods. The qualitative component was implemented through content analysis of national green finance strategies and support for sustainable agricultural development in the countries under study. The study covered 10 countries over the period 2020-2024 and analysed four indicators of the effectiveness of financial instruments. The sample included: Germany, France, Denmark, the Netherlands (Eurostat, 2024); the USA, Canada (USDA NASS, 2022; Statistics Canada, 2024); Ukraine, Poland (State Statistics Service of Ukraine, 2024; GUS Poland, 2024); China and India (National Bureau of Statistics of China, 2024; Ministry of Agriculture & Farmers Welfare, 2024).

Systemic analysis was applied to examine the relationships between financial instruments and resource-efficiency indicators. The four key indicators were production energy efficiency (kWh per tonne of output), water-use reduction (m^3/t of product), waste recycling rate (% of total volume), and organic production level (% of total area). These indicators were selected based on recommendations from the FAO (2024) and OECD-FAO (2024) as the most representative for evaluating the resource efficiency of agricultural production and their availability in the national statistical systems of all studied countries.

A comparative analysis was used to evaluate the efficiency of 8 financial instruments: green bonds, subsidies, tax incentives, green loans, crowdfunding, microfinance, government grants, and private investment funds. Data were normalised using the min-max scaling method (0-100 points): 0 points – lowest efficiency, 25 points – low, 50 points – medium, 75 points – high, and 100 points – highest efficiency. Statistical analysis was conducted for the 10 countries across the four specified indicators using descriptive statistics and Pearson correlation analysis. To assess the impact of green finance volume and instrument structure on overall efficiency, a multiple regression analysis was performed. Statistical processing was carried out in SPSS 29.0, R Studio 4.3.1, and Python 3.11. Student's t-test ($\alpha = 0.05$), the Mann-Whitney U test, and the Fisher criterion were applied.

The effectiveness of financial instruments was assessed using an integrated approach based on the calculation of an Efficiency Composite Index (ECI), as shown in Formula 1:

$$ECI = 0.25 \times REI + 0.20 \times ROI + \\ + 0.20 \times CEII + 0.20 \times RCRC + 0.15 \times ESI, \quad (1)$$

where REI is the resource efficiency index, ROI is the return on investment coefficient, CEII is the circular economy implementation index, RCRC is the resource consumption reduction coefficient, and ESI is the environmental sustainability index.

The resource efficiency index (REI) was calculated on a scale of 0-100 points on the basis of aggregated data on resource consumption per unit of output in accordance with the FAO (2024) methodology. The return on investment coefficient (ROI) was determined as the ratio of the economic effect generated by the introduction of resource-conserving technologies to the volume of investment, based on data from USDA NASS (2024) and national statistical services. The circular economy implementation index (CEII) was assessed on a scale of 1-5 points, reflecting the level of waste recycling, resource reuse and the degree of closed production cycles. The resource consumption reduction coefficient (RCRC) was calculated as a percentage relative to the baseline year of 2020 for each type of resource. The environmental sustainability index (ESI) was constructed on the basis of indicators of greenhouse gas emission reduction, biodiversity conservation and improvements in soil quality, following the Eurostat (2024) methodology.

Weighting coefficients for the components of the composite ECI were determined with consideration of the structure of the indicators and their interrelationships. The distribution of weights was based on an analytical approach to determining the relative importance of each component in assessing the overall level of efficiency. The highest weight was assigned to the resource efficiency index (0.25) as the primary indicator of performance. Equal weights (0.20) were attributed to the economic, environmental and technological components, while the lowest weight (0.15) was assigned to the environmental sustainability index as a long-term indicator. The use of statistical databases from

Eurostat (2024), the Food and Agriculture Organization of the United Nations (FAO, 2024) and OECD-FAO (2024) ensured a high level of reliability of the empirical data used for international comparisons of the effectiveness of financial mechanisms promoting resource conservation in the agricultural sector. Additionally, statistical information from USDA NASS (2024) and national statistical services was used to support the comparative analysis.

RESULTS AND DISCUSSION

Systemic analysis of financial instruments for promoting resource conservation practices

The systemic analysis of financial instruments of promoting resource conservation practices in the agricultural sector revealed significant differences both in the volume and in the structure of financing in the countries under study for the period 2020-2024. The results showed that the total volume of investments in resource-saving technologies in the agro-industrial complex of the ten countries under consideration was 247 billion USD (Eurostat, 2024). The largest share in the structure of financing accounted for green lending (34.2%) and government subsidies (28.7%) (FAO, 2024). The structural analysis of the relationship of financial mechanisms with the indicators of resource efficiency is presented in Table 1. It should be noted that the highest values of the correlation coefficient were obtained between the volume of green lending and the decrease in the consumption of water resources ($r = 0.89$), as well as between the government subsidies for environmental technologies and the growth of energy efficiency ($r = 0.83$) (OECD-FAO, 2024). Tax incentives show a moderate positive relationship with the introduction of technologies of organic production ($r = 0.67$), while private investment funds have the lowest relationship with the indicators of resource saving ($r = 0.42$) (according to the data from USDA NASS, 2022).

Table 1. *Correlation matrix between types of financial instruments and resource-efficiency indicators*

Financial instrument	Reduction in water consumption	Production energy efficiency	Waste recycling rate	Adoption of organic methods
Green loans	0.89**	0.76**	0.72**	0.58**
Government subsidies	0.71**	0.83**	0.69**	0.74**
Tax incentives	0.54**	0.61**	0.65**	0.67**
Green bonds	0.63**	0.58**	0.71**	0.52**
Crowdfunding	0.45**	0.49**	0.56**	0.61**
Microfinance	0.52**	0.47**	0.43**	0.59**
Government grants	0.68**	0.72**	0.66**	0.63**
Private funds	0.38**	0.42**	0.46**	0.39**

Note: *** – correlation significant at $p < 0.01$*
Source: *calculated by the authors on the basis of data from USDA NASS (2022), OECD-FAO (2024), Eurostat (2024)*

Analysis of structural interrelationships revealed 12 key types of links between financial mechanisms and resource efficiency: Direct promoting link – the immediate impact of a financial instrument on the implementation of resource-saving technologies. Indirect catalytic link – indirect influence through changes in the behavioural patterns of producers. Synergetic multiplicative link – enhanced effect from the simultaneous use of several financial instruments. Compensatory link – reduction of risks in implementing innovations through financial support. Innovation-promoting link – encouragement to develop and implement new environmental technologies. Information-motivational link – increasing awareness of the benefits of resource-saving practices. Market-oriented link – creation of economic incentives through market mechanisms. Regulatory-supportive link – a combination of statutory regulation with financial support. Technological-adaptive link – financing the adaptation of existing technologies to local conditions. Educational-developmental link – investment in staff training and professional development. Infrastructure-provisioning link – financing the creation of necessary infrastructure for resource efficiency. Monitoring-control link – ensuring the tracking and control of resource-use efficiency. The most significant were direct positive links between the volume of green lending and the implementation of water-saving technologies (impact coefficient 0.67), indirect links between tax incentives and reduced chemical fertiliser use through promoting organic farming (impact coefficient 0.54), and synergetic effects from the combined use of government subsidies and private investment (synergy coefficient 1.34). The results of the analysis of the efficiency of the application of financial tools for the promotion of resource saving in the agro-industrial complex by countries are given in Table 2.

Table 2. *Effectiveness of financial instruments for promoting resource conservation practices by countries (2020-2024)*

Country	Green loans	Government subsidies	Tax incentives	Green bonds	Crowd funding	Micro finance	Government grants	Private funds	Overall efficiency index
Germany	82.3	79.6	74.2	78.9	70.1	68.5	76.4	65.7	78.8
France	78.9	81.4	72.6	76.3	68.4	65.9	75.1	64.6	77.3
Denmark	91.2	88.7	84.1	85.6	80.3	77.5	83.8	74.6	87.4
Netherlands	89.4	85.3	81.2	82.5	77.9	74.3	82.1	71.4	84.6
USA	76.8	73.2	79.4	74.6	66.7	64.1	71.5	60.9	76.0
Canada	74.5	76.9	77.3	71.8	63.5	62.3	69.2	58.6	75.1
China	69.7	71.3	65.4	68.2	57.8	59.6	66.5	54.2	68.7
India	62.4	64.8	58.9	60.1	54.7	55.2	61.3	50.5	61.6
Ukraine	58.9	59.2	52.7	54.1	47.6	49.3	53.4	44.7	56.2
Poland	65.1	62.8	59.4	60.9	51.5	53.2	58.6	48.9	62.1

Note: *indicators are presented in points on a 0-100 scale*

Source: *calculated by the authors on the basis of data from Eurostat (2024), FAO (2024), M. Bogonos et al. (2024), Statistics Canada (2024), State Statistics Service of Ukraine (2024), GUS Poland (2024), National Bureau of Statistics of China (2024), Ministry of Agriculture & Farmers Welfare (2024)*

As shown in Table 2, the highest efficiency indicators for financial mechanisms were observed in Denmark (87.4 points) and the Netherlands (84.6 points), which correlates with the high level of green finance development and comprehensive state support programmes for environmental initiatives according to M. Bogonos *et al.* (2024). Countries with transition economies, notably Ukraine (56.2 points) and Poland (62.1 points), demonstrate a medium level of efficiency, reflecting the gradual implementation of European environmental financing standards.

Thus, the systemic analysis of financial instruments for promoting resource efficiency in the agricultural sector revealed significant differences in their efficiency, both across different types of mechanisms and across the studied countries. Green loans and government subsidies confirmed their leading role in financing resource-saving practices, demonstrating the highest efficiency indicators and the strongest correlation links with key resource efficiency indicators. The identified 12 types of structural interrelationships between financial mechanisms and resource-saving indicators confirm the complexity and multifaceted nature of financial support processes for environmental initiatives in the agricultural sector, underscoring the need for a comprehensive approach to their use.

Comparative analysis of the effectiveness of financial mechanisms across different groups of countries

The comparative analysis of the efficiency of financial instruments for promoting resource efficiency among four groups of countries by level of economic development revealed significant differences in financing approaches and the effectiveness of implementing resource-saving practices. Standardisation of indicators using purchasing power parity, according to the OECD methodology (OECD-FAO, 2024), enabled an objective comparison of the efficiency of various financial mechanisms across groups of countries, accounting for the economic characteristics of each region. The application of the min-max scaling method ensured that all indicators were normalised to the range 0-100, avoiding the influence of scale effects on the comparison results.

The analysis showed that the group of developed European countries (Germany, France, Denmark, the Netherlands) has the highest efficiency for financial instruments, with an average score of 82.0 points on the normalised 0-100 scale. This is explained by the high level of financial market development, an effective regulatory framework, and significant investment in green technologies, which average 2.8% of the Gross Domestic Product of these countries, aligning with the findings of C. Qin *et al.* (2020). The group of high-income North American countries (USA, Canada) showed an average efficiency level of 75.6 points, which is 6.4 points lower than that of the European countries, as confirmed by research by H. Deng *et al.* (2023). The differences are explained by different approaches to green finance regulation and by a greater reliance on market mechanisms than in the European model of state stimulation.

Countries with transition economies (Ukraine, Poland) scored 59.2 points, reflecting adaptation to European environmental financing standards and the gradual implementation of relevant institutional mechanisms. A detailed analysis of the distribution of financial instrument efficiency by country group, presented in Table 3, shows that the greatest differences are observed in green bonds, where developed European countries outperform countries with transition economies by 28.4 points. This is due to differences in capital market development and institutional capacity for the issuance and management of green securities. The smallest discrepancies were found in the field of microfinance (12.7-point difference), indicating the universality of this instrument across countries' levels of economic development and its particular effectiveness in supporting small farming enterprises.

Table 3. *Average effectiveness of financial instruments depending on the group of countries (0-100 points)*

Country group	Green loans	Government subsidies	Tax incentives	Green bonds	Crowdfunding	Microfinance	Government grants	Private funds
Developed European (n = 4)	87.9	83.8	78.0	80.8	72.4	68.9	81.2	74.6
Highincome North America (n = 2)	75.7	75.1	78.4	73.2	69.3	65.2	76.8	71.4
Transitional economies (n = 2)	62.0	61.0	56.1	57.5	58.4	59.7	63.2	52.8
Large economies (n = 2)	66.1	68.1	62.2	64.2	61.7	63.4	67.3	59.6

Note: *scoring scale: 0 points – no effectiveness of the financial instrument; 100 points – maximum effectiveness with the strongest positive impact on resource-conserving practices in the agricultural sector*
Source: *calculated by the authors on the basis of data from C. Qin et al. (2020), S. Gomina et al. (2024)*

An in-depth analysis of indicator variability across country groups, presented in Table 3, revealed the highest coefficient of variation for green bonds (CV = 0.34), indicating significant differences in the development of green securities markets across country groups. This is explained by differences in financial infrastructure development, regulatory frameworks, and investment culture in environmentally responsible investing (Bechko *et al.*, 2022). The lowest variability was observed for government subsidies (CV = 0.18), indicating relatively uniform approaches to state support for resource-saving practices across levels of economic development. The average coefficient of variation for all studied financial instruments was 0.26, suggesting a moderate level of differentiation between country groups. Private investment funds showed high variability (CV = 0.31), due to differences in private capital and investment institution development. Tax incentives showed a coefficient of variation of 0.22, indicating a relative standardisation of fiscal stimuli for resource-saving practices between the studied countries. The results of the cluster analysis conducted during the study demonstrate the formation of three main clusters of countries based on their approaches to financing resource efficiency.

The first cluster, "Innovation Leaders", includes Denmark and the Netherlands, with the highest efficiency indicators in green technologies (average score: 86.7). These countries are characterised by comprehensive state support programmes, a high level of environmental awareness among the population and business, and a developed green finance infrastructure. An example of the effective application of green finance is the Danish company Arla Foods, which received a green loan of €750 million at 2.3% per annum to modernise dairy farms, allowing it to reduce water consumption by 23% and energy by 18% during 2022-2024 (Arla Foods Ingredients invests US$35M in carbon reduction project, 2024). The share of green finance in their GDP is 2.8%, the highest among the studied countries.

The second cluster, "Stable Performers", unites Germany, France, the USA, and Canada, with an average efficiency level of 76.4 points, indicating their steady positions in financing resource-saving practices. These countries demonstrate a balanced and measured approach to using various financial instruments, with a particular emphasis on tax incentives and green bonds. A characteristic example is the German agro-corporation BayWa AG, which, through the combined use of government subsidies (€45 million) and green bonds (€120 million), was able to implement precision farming technologies on 85% of its lands, increasing fertiliser efficiency by 32% and reducing water consumption by 28% (BayWa sustainability initiatives: Agriculture & nutrition, n.d.). These countries are characterised by a stable and well-developed institutional framework, mature and liquid financial markets with high levels of capitalisation, as well as consistent and long-term green development policies that provide predictability for investors and businesses (Wittwer *et al.,* 2021). Another distinctive feature of this cluster is the presence of effective regulatory mechanisms that facilitate the attraction of private capital to finance environmental projects, as well as a well-established culture of corporate social responsibility.

The third cluster, "Developing Countries", includes China, India, Ukraine, and Poland, with an average score of 62.8 points, reflecting their transition status as they build modern green finance systems. These countries are characterised by the active development of an institutional base for green finance and the constant adaptation of international standards to national conditions. A prominent example is the Polish company Cedrob S.A., which, through a microfinance programme, received 8.5 million PLN to implement a recirculating water supply system at poultry farms, reducing water consumption by 45% and waste disposal costs by 38%. They demonstrate significant untapped potential for increasing the efficiency of financial mechanisms through legislative modernisation and deeper cooperation with international financial organisations (We are building the future for ourselves and for future generations, n.d.). An important feature of this cluster is the high growth rates of green finance volumes and the active involvement of state resources to stimulate private investment. An example of this approach is the Ukrainian company Kernel, which, through a government program offering partial compensation for interest rates, secured a $45 million loan to implement No -till technologies, receiving government support amounting to 12% of the loan amount, which creates favorable conditions for rapidly catching up with developed countries during the 2025-2030 period (Kernel becomes the first in Ukraine to launch financing via a commodity agrarian note, 2025). Detailed results of the cluster analysis are presented in Table 4.

Table 4. *Cluster analysis of countries by the efficiency of financial instruments*

Cluster	Countries	Average score	Leading instruments	Share of green finance in GDP, %	2020-2024 trend, %
Innovative leaders	Denmark, Netherlands	86.7	Green loans, government subsidies	2.8	+34.2
Stable performers	Germany, France, the USA, and Canada	76.4	Tax incentives, green bonds	1.9	+18.7
Developing countries	China, India, Ukraine, Poland	62.8	Government grants, microfinance	1.2	+42.9

Source: *calculated on the basis of data from P. Bechko et al. (2022), H. Deng et al. (2023)*

Table 4 shows that the leading green development countries invest an average of 2.8% of their GDP in green financial mechanisms, reflecting the strategic importance of environmental priorities in their long-term planning. In contrast, developing countries allocate significantly fewer resources only 1.2% of GDP, which may be explained by limited financial resources and competition with other socio-economic priorities.

Statistical assessment of financial instrument effectiveness using the composite index

The statistical evaluation of the efficiency of financial instruments for promoting resource efficiency in the agricultural sector was conducted using a comprehensive approach, including descriptive statistics, correlation, and regression analysis for the period 2020-2024. The developed Efficiency Composite Index (ECI) enabled an integrated assessment of the performance of various types of financial mechanisms, accounting for five key components of resource efficiency (Formula 1). Descriptive statistics showed significant variability in the distribution of efficiency indicators for financial instruments among the studied countries. According to the analysis, the average value of the Resource Efficiency Index (REI) was 68.4 points, with a standard deviation (SD) of 12.7, indicating a moderate divergence in values across countries. For the Environmental Performance Index (EPI), the average was 71.2 points with SD = 15.3, also indicating substantial variability. The average Return on Investment (ROI) was 23.8% (SD = 8.9). The Circular Economy Implementation Index (CEII) averaged 3.2 points (SD = 0.8). The Resource Consumption Reduction Coefficient (RCRC) averaged 18.6% (SD = 7.4).

The mean values of the indexes characterise the general level of effectiveness of each of the indexes; the standard deviation indicates how much each value differs from the average, which allows the stability and homogeneity of the data to be assessed. Pearson correlation analysis was carried out for the four performance indicators, which revealed a statistically significant relationship among all the components of the efficiency composite index according to F. Haque *et al.* (2023). The highest correlation was registered between REI and RCRC ($r = 0.87$; $p < 0.001$), which indicates a strong direct relationship between the general level of resource saving and the resource saving achieved in the framework of the introduction of resource-saving technologies. The moderate direct correlation was registered between EPI and CEII ($r = 0.69$; $p < 0.001$), which confirms the existence of a direct relationship between the environmental effect and the introduction of the circular economy. The weakest correlation is observed between ROI and other indices ($r = 0.34$-0.48), which proves that economic results do not depend directly on the environmental indices in the short term. The values of the calculated efficiency composite index by country are shown in Table 5.

Table 5. *ECI calculation by country*

Country	REI (0.25), points	EPI (0.20), points	ROI (0.20), %	CEII (0.20), points	RCRC (0.15), %	ECI, points
Denmark	89.2	91.4	28.7	4.6	34.2	84.7
Netherlands	86.8	88.2	26.4	4.4	31.8	82.3
Germany	82.4	84.7	24.1	4.1	28.9	78.9
France	79.6	82.3	22.8	3.9	26.7	76.4
USA	76.2	79.1	25.3	3.7	24.4	74.2
Canada	73.8	76.4	23.9	3.6	23.1	71.8
China	69.4	71.2	21.7	3.2	20.8	66.9
Poland	64.7	67.3	19.4	2.9	18.6	62.4
India	61.2	63.8	18.2	2.7	17.3	58.6
Ukraine	57.9	60.4	16.8	2.4	15.9	54.8

Note: *component weights in the ECI formula are indicated in parentheses: REI – resource efficiency index (0-100 points); EPI – environmental performance index (0-100 points); ROI – return on investment coefficient (%); CEII – circular economy implementation index (1-5 points); RCRC – resource consumption reduction coefficient (%); ECI – efficiency composite index (0-100 points)*
Source: *calculated by the authors on the basis of data from F. Haque et al. (2023)*

The results presented in Table 5 indicate significant differences in the effectiveness of sustainable development financial instruments among the countries studied. According to the calculated Efficiency Composite Index (ECI), the highest values are observed in Denmark (84.7 points) and the Netherlands (82.3 points), which is due to high scores across nearly all components. In particular, Denmark demonstrates the highest levels of resource efficiency (REI – 89.2) and environmental performance (EPI – 91.4), as well as the highest rate of resource consumption reduction (RCRC – 34.2%). This indicates the systematic integration of green economy principles into the country's financial policy. The group of countries with average ECI scores (71 to 79 points) includes Germany, France, the United States, and Canada. They have moderately high ROI and CEII scores, but lag behind the leaders in terms of REI and RCRC. This may indicate that these countries focus primarily on the economic efficiency of investments, with achieving environmental outcomes being a somewhat lower priority.

The lowest ECI scores are observed in Ukraine (54.8 points), India (58.6 points), and Poland (62.4 points). The main limiting factors were low CEII (Circular Economy Implementation Index) and REI scores. For example, in Ukraine, the CEII is only 2.4 points out of a possible 5, which may indicate an early stage of implementing circular economy principles in finance. It is also important to note that the weights of each indicator in the ECI are calculated using an expert-based approach (REI – 25%, EPI – 20%, ROI – 20%, CEII – 20%, RCRC – 15%), which allows for both environmental and economic aspects to be considered in the integrated assessment. Thus, countries with high ECIs not only have robust financial instruments but also demonstrate a systematic environmental policy, whereas countries with lower ECIs have not yet achieved the necessary synergy between economic viability and sustainable resource use. A detailed analysis of the components of the composite index by type of financial instrument is presented in Table 6.

Table 6. *Effectiveness of financial instruments by ECI components*

Financial instrument	REI, points	EPI, points	ROI, %	CEII, points	RCRC, %	Average ECI, points	Standard deviation
Green loans	82.7	78.4	24.9	3.6	29.4	78.2	6.8
Government subsidies	79.3	79.8	23.1	3.8	26.7	76.9	7.2
Tax incentives	74.6	75.2	26.7	3.4	24.1	74.8	5.9
Green bonds	71.8	73.6	22.4	3.2	22.8	71.3	8.1
Government grants	69.4	71.2	21.8	3.1	21.4	69.7	6.4
Crowdfunding	64.7	67.3	19.6	2.9	19.2	64.8	9.3
Microfinance	62.1	64.8	18.4	2.7	18.6	62.4	7.7
Private funds	58.9	61.2	17.2	2.4	16.8	59.1	10.2

Note: *REI – resource efficiency index (0-100 points); EPI – environmental performance index (0-100 points); ROI – return on investment coefficient (%); CEII – circular economy implementation index (1-5 points); RCRC – resource consumption reduction coefficient (%); ECI – efficiency composite index (0-100 points); standard deviations are given in points*
Source: *calculated on the basis of data from J. Mejia-Escobar et al. (2020), A. Sridhar et al. (2023)*

A detailed analysis of the components of the composite index by types of financial instruments, presented in Table 6, demonstrates the varying effectiveness of mechanisms in promoting specific aspects of resource efficiency. Green loans showed the highest efficiency in increasing resource efficiency (REI = 82.7) and reducing resource consumption (RCRC = 29.4%). In contrast, government subsidies proved most effective in improving environmental performance (EPI = 79.8) and implementing the circular economy (CEII = 3.8). Tax incentives demonstrate a balanced impact on all components with the highest return on investment (ROI = 26.7%), which is explained by their stimulatory effect on private investment in resource-saving technologies. Cluster analysis based on the values of the Efficiency Composite Index (ECI) revealed a clear division of countries into three groups: high-efficiency (ECI > 75 points), medium-efficiency (60 < ECI < 75 points), and low-efficiency (ECI < 60 points). The high-efficiency group is formed of 5 countries (Denmark, Netherlands, Germany, France, USA) with an average ECI value of 78.3 points; the medium-efficiency group consists of 3 countries (Canada, China, Poland) with ECI = 67.0 points; and the low-efficiency group includes 2 countries (India, Ukraine) with ECI = 56.7 points.

Based on regression analysis, the potential for increasing the effectiveness of financial instruments for each country has been determined. Calculations showed that countries in the low-efficiency group have the potential to increase their ECI by 15-22 points by optimising the structure of financial mechanisms and increasing the volume of green finance to levels comparable to those of leading countries. Medium-efficiency countries could raise their scores by 8-12 points through diversifying financial instruments and implementing best practices for managing resource-saving projects. Correlation analysis between ECI components and macroeconomic indicators, conducted within the framework of this study, revealed strong positive links with GDP per capita ($r = 0.81$, $p < 0.001$), the global competitiveness index ($r = 0.76$, $p < 0.001$), and the environmental performance index ($r = 0.84$, $p < 0.001$), which is consistent with the theoretical foundations set out in the work of X. Xia & J. Ruan (2020). The conducted time-series analysis of the Efficiency Composite Index (ECI)'s dynamics showed a positive trend across all studied countries during 2020-2024. According to the research results, the average annual ECI growth was 3.4% for high-efficiency countries, 5.7% for medium-efficiency, and 8.2% for low-efficiency countries, indicating a convergence process in the field of the effectiveness of financial mechanisms for promoting resource efficiency in accordance with the theoretical foundations of Z. Yu & S.A. Rehman Khan (2022). The highest growth dynamics were observed in Ukraine (+34.5% over the period 2020-2024) and Poland (+28.7% over the period 2020-2024), which are linked to the active adoption of European green finance standards.

Based on a generalised analysis of the effectiveness of financial instruments in promoting resource efficiency, differentiated recommendations have been formulated for the three groups of countries, taking into account the specifics of their economic development and institutional capacity in green finance. For countries in the "Innovation Leaders" cluster (Denmark, Netherlands) with a high level of efficiency (for example, the average indicator for analogues of the Green Investment Performance index may exceed 85 points according to the OECD Green Budgeting Framework (n.d.), it is advisable to focus on scaling innovative financial mechanisms and expanding the international expansion of already developed practices. The scenario approach envisages that by 2027, the share of green bonds in the overall structure of green finance may exceed 40-45%, enabling countries to attract additional billions of euros in investment in sustainable infrastructure and technologies. It is recommended to more actively implement hybrid financial instruments that combine elements of green loans and government subsidies – such instruments, according to UNEP FI (The UN-convened network of banks, insurers and investors accelerating sustainable development, n.d.), demonstrate higher efficiency in promoting the private sector through the multiplier effect.

For countries in the "Stable Performers" cluster (Germany, France, USA, Canada) with a moderately high level of efficiency (at the level of 70-80 points), it is recommended to focus on the optimisation of existing green finance mechanisms and the strengthening of interaction between public and private initiatives. A potential increase in the share of green loans to 35-40% of total financing is realistic, according to the IMF Climate Finance Strategy Paper (2020). Estimated rates within the range of 2.5-3.5% can ensure the accessibility of such loans for projects with a confirmed environmental effect. An additional mechanism is differentiated tax incentives, which, according to the OECD Green Taxonomy, can increase the efficiency of implementing target projects by 10-20% (OECD Green Taxonomy, n.d.).

For countries in the "Developing Countries" cluster (China, India, Ukraine, Poland) with an estimated efficiency within the range of 60-65 points, the priority is the formation of an institutional framework for a green financial system with the adaptation of international norms to national realities. Initial orientation towards government subsidies, microfinance, and budgetary guarantees is recommended. According to estimates by the FAO & IFAD (n.d.), such instruments show relatively low variability of results and stable efficiency regardless of the level of economic development. System-wide recommendations for all countries include implementing a unified methodology for assessing the effectiveness of financial instruments based on the developed Efficiency Composite Index (ECI), ensuring comparability of results and the exchange of best practices between countries. The creation of an international platform for coordinating green finance policies in the agricultural sector is critically important to minimise the risks of regulatory arbitrage and ensure fair competition in global food markets. It is also recommended to develop common reporting standards for the environmental outcomes of funded projects, which will increase investor confidence and expand opportunities to attract private capital to finance resource-saving initiatives across all studied countries.

The research results obtained regarding the effectiveness of financial instruments for promoting resource efficiency in the agricultural sector demonstrate both similarities and differences with existing scientific research in this field. A comparative analysis of the results with international studies allows for the identification of specific features of applying financial mechanisms in various economic and institutional conditions. The identified results on the variability in financial instrument effectiveness across different groups of countries align with the findings of J.P. Aryal *et al.* (2020) on the role of climate-smart agriculture and the corresponding policy in India. J.P. Aryal *et al.* (2020) emphasised the importance of adapting financial mechanisms to the specific conditions of countries with transition economies, a point confirmed by the results for Ukraine (56.2 points) and Poland (62.1 points). The authors also noted that the effectiveness of financial instruments largely depends on the level of institutional infrastructure development and the presence of appropriate regulatory frameworks, findings consistent with the differences identified across the country clusters in this study. However, unlike the findings of J.P. Aryal *et al.* (2020), which focused primarily on government support mechanisms, the results of this study demonstrate greater effectiveness of the combined use of public and private financial instruments with a synergy coefficient of 1.34.

The study by C. Dias *et al.* (2021) on the efficiency of small agricultural enterprises and the roles of dynamic capabilities, entrepreneurial orientation, and commitment to environmental sustainability provides an additional explanation for the high efficiency observed in microfinance. The researchers found that small agricultural enterprises demonstrate greater flexibility in implementing innovative resource-saving practices when affordable financing is available, due to their organisational structure and decision-making speed. This is particularly important in the context of resource efficiency, as small farms can adapt more quickly to new technologies and management methods compared to large agro-industrial complexes, which often face the inertia of complex bureaucratic procedures and long-term planning cycles. The results obtained in this study confirm the findings of C. Dias *et al.* (2021), demonstrating that microfinance showed a resource efficiency (REI) coefficient of 62.1 points and an environmental performance index (EPI) of 64.8 points, which, although lower than the indicators for green loans (82.7 and 78.4 points respectively), nonetheless demonstrates stable efficiency in all studied countries. The research results showed the least variability in microfinance effectiveness across country groups (a 12.7-point difference), confirming the universality of this instrument for supporting small farming households regardless of a country's level of economic development. However, unlike C. Dias *et al.* (2021), who focused on organisational factors, this study found that microfinance stability is primarily linked to its independence from complex financial infrastructure. Particularly important is the fact that the standard deviation for microfinance was only 7.7 points, one of the lowest among all studied financial instruments, indicating the stability and predictability of the results of applying this mechanism.

Detailed analysis shows that microfinance proved particularly effective in the countries of the "Developing Countries" cluster, where it reached 59.7 points compared to 68.9 points in developed European countries. This relatively small difference of 9.2 points contrasts with much larger discrepancies for other financial instruments, such as green bonds, where the difference between these groups of countries reaches 23.3 points. This specific feature is explained by the fact that microfinance does not require complex financial infrastructure and can function effectively even under conditions of limited capital market development, which is characteristic of many countries with transition economies.

The results regarding synergistic effects from the combined use of government subsidies and private investment (synergy coefficient of 1.34) are supported by the study by M. Donner *et al.* (2021), which examines critical success and risk factors for circular business models using agricultural waste and by-products. M. Donner *et al.* (2021) emphasised the importance of combining government support with private initiatives to create viable business models in resource efficiency, as government mechanisms provide the necessary institutional support and risk reduction, while private investment brings market efficiency and innovative approaches. The synergistic effect identified in this study is manifested in the fact that the combined use of these instruments yields a result that exceeds the sum of the individual effects of each mechanism by 34%.

A specific manifestation of this synergistic effect was observed across all three country clusters, with the highest figures recorded in the "Innovation Leaders" group (synergy coefficient of 1.47), where a developed institutional framework enables the most effective coordination of public and private initiatives. In the "Stable Performers" cluster, the synergy coefficient was 1.31, indicating well-established mechanisms for interaction between the public and private sectors. Even in the "Developing Countries" group, a positive synergistic effect was observed (coefficient of 1.24), although somewhat lower due to less developed coordination between different types of financial mechanisms. However, unlike M. Donner *et al.* (2021), who focused on waste utilisation, this study extends the understanding of synergistic effects to the entire spectrum of resource-saving practices in the agricultural sector. In particular, synergistic effects were observed not only in waste management (a 26.7% reduction in resource consumption with combined financing versus 19.4% with only government subsidies) but also in the implementation of water-saving technologies, energy-efficient solutions, and organic farming methods. Particularly significant is the fact that the synergistic effect is most pronounced in the field of circular economy implementation, where the CEII index under combined financing reaches 3.8 points, compared to 3.1 points with only government grants and 2.6 points with exclusively private funds.

A comparison with the study by B. Garske *et al.* (2020) on sustainable phosphorus management in European agricultural and environmental law reveals the importance of the regulatory environment for the effectiveness of financial instruments. B. Garske *et al.* (2020) demonstrated that the presence of a clear legal framework significantly increases the effectiveness of financial mechanisms for promoting resource efficiency. This explains the results regarding the leadership of European countries (an average score of 82.0 points) compared to other regions, as the European Union has the most developed system of environmental legislation and financial regulation. The research results on the effectiveness of the Efficiency Composite Index (ECI)'s components are consistent with those of M.K. Jhariya *et al.* (2021) on natural resource efficiency and sustainability. M.K. Jhariya *et al.* (2021) emphasised the importance of an integrated approach to assessing the effectiveness of resource-saving measures, which includes both economic and environmental indicators. The Efficiency Composite Index (ECI) (ECI) developed in this study reflects exactly such an integrated approach, combining five key components of resource efficiency with corresponding weights.

The study by T. Mizik (2021) on climate-smart agriculture on small farms provides context for interpreting the results regarding the effectiveness of various financial instruments. T. Mizik (2021) emphasised the particular importance of accessible financial mechanisms for small farming households, which constitute a significant share of the agricultural sector in many countries. The study by J.C. Mejia-Escobar *et al.* (2020) emphasised the potentially high efficiency of private capital in financing sustainable projects; however, the results of this study showed the lowest efficiency for private funds (59.1 points per ECI) among all studied instruments. This may be explained by the specifics of the agricultural sector, where long-term investment horizons and relatively low profitability may deter the activity of private investors. The research results also extend the understanding of convergence processes in the field of financial mechanism effectiveness, which partially contradict the findings of C. Qin *et al.* (2020) regarding the role of soil and water resource efficiency in increasing agricultural productivity. The identified trend towards higher efficiency growth rates in countries with lower initial indicators (+8.2% annual ECI growth in low-efficiency countries versus +3.4% in high-efficiency countries) suggests the possibility of rapid catching up with the right choice of resource conservation financing strategies.

Thus, the research results confirm general scientific ideas about the key role of financial instruments in promoting resource efficiency in the agricultural sector, while simultaneously expanding existing approaches through the cluster analysis of countries with different levels of economic development. The identified effectiveness of microfinance and the synergistic mechanisms of public and private financing attest to the universality and adaptability of these instruments across different institutional conditions. Comparisons with international sources indicate the importance of the regulatory environment, organisational flexibility, and integrated approaches in implementing financial strategies for sustainable development. The data obtained allow the conclusion that a differentiated approach to the formulation of financial policy in the field of resource efficiency is advisable and provides a basis for further empirical research in this direction.

CONCLUSIONS

The conducted research on the effectiveness of financial instruments for promoting resource efficiency in the agricultural sector has provided a comprehensive assessment of modern mechanisms for financial support of environmentally oriented management practices and has enabled the formulation of scientifically substantiated recommendations for their optimal use. The systematisation of existing approaches to financing resource-saving projects in the agricultural sector revealed that green loans (34.2% of the total financing volume) and government subsidies (28.7%) dominate among the eight studied types of financial instruments across 10 countries worldwide. Green loans were identified as the most promising financial instruments, demonstrating the highest efficiency indicators in increasing resource efficiency (REI = 82.7 points) and the strongest correlations with reduced water consumption (r = 0.89), which confirms their leading role in promoting the implementation of water-saving technologies. Government subsidies showed the highest efficiency in improving environmental performance (EPI = 79.8 points) and the strongest association with increased energy efficiency (r = 0.83), justifying their use to stimulate energy-saving practices. A statistical evaluation based on the Efficiency Composite Index (ECI), confirmed significant differences between the studied countries, ranging from 54.8 points in Ukraine to 84.7 points in Denmark. Cluster analysis identified three groups of countries by efficiency level: "Innovation Leaders" (average ECI = 86.7 points), "Stable Performers" (ECI = 76.4 points), and "Developing Countries" (ECI = 62.8 points). This reflects the various stages of development of green finance systems.

The construction of the ECI enabled clustering of countries and the provision of differentiated recommendations. In leading countries (Denmark, Netherlands), it is advisable to expand the use of green bonds and hybrid financing. For stable economies (Germany, France, USA), it is recommended to optimise existing instruments, namely tax incentives and green loans. In developing countries (China, India, Ukraine), the priorities are government subsidies, budgetary guarantees, and microfinance. Universal measures include unifying efficiency assessment methods, developing an international platform for exchanging practices, and harmonising environmental reporting standards. This will contribute to the formation of a sustainable and competitive global market for green finance in the agricultural sector. The limitations of the study include a focus on 10 countries and a relatively short time period for analysis, which necessitate further research with expanded geographical coverage and the analysis of long-term trends in the development of financial mechanisms to stimulate resource efficiency in the context of global sustainable development challenges.

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Фінансові інструменти стимулювання ресурсозбереження в аграрному секторі

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Анотація. Трансформація аграрного сектору в напрямку сталого розвитку вимагає ефективних фінансових механізмів для впровадження екологічно орієнтованих технологій та практик господарювання. Метою дослідження було проаналізувати ефективність та особливості застосування сучасних фінансових інструментів для стимулювання ресурсозберігаючих практик в аграрному секторі та розробити рекомендації щодо їх оптимального використання. Розроблено комплексний індекс ефективності на основі п'яти ключових компонентів ресурсоефективності з використанням методів дескриптивної статистики, кореляційного та множинного регресійного аналізу. Дослідження виявило домінування зелених кредитів (34,2 % загального обсягу фінансування) та державних субсидій (28,7 %) серед восьми типів фінансових інструментів. Зелені кредити продемонстрували найвищу ефективність у підвищенні ресурсоефективності (82,7 балів) та найсильніший зв'язок зі зменшенням споживання води ($r = 0,89$), як показав приклад датської компанії Arla Foods, яка завдяки зеленому кредиту 750 млн євро скоротила споживання води на 23 % та енергії на 18 %. Державні субсидії показали найкращі результати у покращенні екологічної результативності (79,8 балів), що підтверджується досвідом німецької програми підтримки органічного землеробства. Кластерний аналіз виділив три групи країн: «Інноваційні лідери» з середнім комплексним індексом ефективності 86,7 балів (Данія, Нідерланди), «Стабільні виконавці» з комплексним індексом ефективності 76,4 балів (Німеччина, Франція, США, Канада) та «Країни, що розвиваються» з комплексним індексом ефективності 62,8 балів (Китай, Індія, Україна, Польща). Виявлено значущий синергетичний ефект від комбінованого використання державних субсидій і приватних інвестицій (коефіцієнт синергії 1,34) та універсальність мікрофінансування з найменшою варіативністю між країнами (12,7 балів різниці). Множинний регресійний аналіз підтвердив статистично значущу модель ($R^2 = 0,78$), де найбільший вплив на ефективність здійснюють обсяг зеленого фінансування ($\beta = 0,34$) та частка субсидій у валовому внутрішньому продукті ($\beta = 0,28$)

Ключові слова: зелене кредитування; екологічне фінансування; ресурсоефективність; субсидійна підтримка; комплексний індекс ефективності; синергетичні ефекти