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Mechanisms for managing the financing of energy-efficient solutions in agricultural enterprises

Abstract. The purpose of this study was to establish approaches to the rational use of financial resources for the introduction of energy-saving technologies in agricultural production considering the operational characteristics of agricultural enterprises. In the course of the study, a comprehensive theoretical and analytical analysis of the mechanisms for financing energy-efficient measures was carried out, the availability of various types of financial support and criteria for the effectiveness of financial management were evaluated. Special attention was paid to the analysis of the state programme "Affordable loans 5-7-9%", under which in 2024 agricultural enterprises received UAH 46.9 billion in loans, attracting 8,750 participants, and the total volume of bank lending to the agricultural sector amounted to more than UAH 104.5 billion. The role of international donors and grant programmes was also investigated, including support from the Food and Agriculture Organization in partnership with the European Union, the United States Agency for International Development, and the Ukraine – Local Empowerment, Accountability and Development programme, which contributed to the development of energy-efficient projects in the agricultural sector. The practical part of the study was based on the analysis of financial mechanisms and management decisions of the agricultural holding Myronivskyi Hlibproduct, in particular on the implementation of biogas complexes Biogas Ladyzhyn and Oril-Lider, which enabled a comprehensive assessment of the current financing models. The

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24 MW Biogas Ladyzhyn complex provided electricity to more than 35,000 households annually, meeting about 40% of the needs of the agroindustrial cluster, while the payback period of the project was 7-8 years. The results showed that the combination of domestic resources, bank loans, state support, and international assistance created effective conditions for the modernisation of production and the introduction of innovative technologies. The practical significance of the study lied in the possibility of using its results to improve the system of financing energy-efficient projects, improve the efficiency of resource management, and support the sustainable development of the agricultural sector in the future

Keywords: investment; biogas; credit; resource; modernisation

INTRODUCTION

Current challenges caused by rising energy costs, climate change, geopolitical instability, and the need to adapt to sustainable development standards require a rethink of approaches to energy consumption in the agricultural sector. Agricultural enterprises, as energy-intensive business entities, are forced to implement solutions that promote energy efficiency to optimise costs, reduce dependence on fossil fuels, and reduce the environmental impact. However, the implementation of such solutions involves significant investment, which is especially difficult in conditions of economic instability and limited access to financial resources.

Inefficiency of management decisions on the introduction of energy-saving technologies in innovation-oriented structures reduces their competitiveness and environmental compliance. This topic was studied by S.M. Lutkovska *et al.* (2024), who justified the importance of digitalisation of energy management, implementation of Smart Grid, and development of managerial competencies. They stressed the need to integrate technological solutions with the management system to achieve energy efficiency. However, the mechanisms for financing energy efficiency at the level of agricultural enterprises remain insufficiently studied, which requires further research on adapting management models to the specifics of agriculture.

Low financial stability of enterprises, concentration of assets in large companies, and limited investment hinder the modernisation of energy infrastructure. This issue was investigated by R. Kostyrko *et al.* (2021), who proved that the liberalisation of the electricity market contributed to lower prices, increased competition and innovation. However, generation remains profitable, while distribution shows financial instability. Despite the active investment, there is a lack of transparent financing mechanisms for small and medium-sized enterprises, which requires further research on the effectiveness of financial instruments and the role of integrated reporting. Imperfect financial instruments and uneven access to resources hinder the implementation of energy-efficient solutions in Ukraine. A.V. Litvinenko (2021) analysed the effectiveness of the green tariff, loans, grants, ESCO agreements (energy service company agreements) and the prospect of introducing green bonds. The researcher showed the positive impact of these instruments on energy savings and emissions reduction, but pointed out the risks of financial instability and bank congestion. Balancing funding and support for small initiatives require further study.

Financing renewable energy in conditions of limited resources and destroyed infrastructure remains a critical challenge for ensuring Ukraine's energy security. Y. Petlenko (2024) explored the possibilities of government subsidies, private capital, international programmes, and innovative mechanisms, such as guarantees of green loans. The researcher proved that the successful implementation of projects depends on a combination of political will, transparent rules, and external support. However, approaches to harmonisation with EU requirements, assessment of the effectiveness of financing in crisis conditions, and prevention of non-ecological investments need to be clarified. Current conditions for energy development require increased investment in renewable energy sources, which was studied by H.O. Pudycheva (2020), analysing the effect of green tariffs, tax incentives, network

connection mechanisms, bank loans, and international grants. The researcher stressed the importance of harmonising legislation, reducing risks for investors, and expanding community participation. Simultaneously, the issues of access to long-term financing, lack of coordination between market participants and adaptation of support tools to the stages of technology development remain unresolved.

Financial instability of the agricultural sector and limited long-term investment hinder the sustainable development of enterprises. This was investigated by S. Boiko *et al.* (2020), who evaluated the structure of financial resources of agricultural enterprises of Ukraine for 2010-2018, identifying three periods with different trends in the share of equity, credit burden, and payment discipline. The researchers proved that equity remains the main source of financing, but since 2015, the role of current liabilities has been increasing against the background of a decrease in long-term investments. The lack of an effective mechanism for long-term lending, insufficient risk assessment by banks, and exchange rate fluctuations remain unresolved issues that require additional analysis and systematic reform.

The unstable economic environment and weak investment climate make it difficult to finance innovative projects in agriculture. R. Myniv & R. Batyuk (2023) analysed the main sources of investment (self-financing, loans, leasing, project financing), identified external and internal risks, and proposed a system of principles of the investment and innovation mechanism. They also developed an approach to evaluating the effectiveness of innovations by type of effect. But the tools for adapting these mechanisms to crisis conditions and attracting foreign capital remain rather neglected. Low efficiency of energy use in industrial enterprises leads to overspending and an increase in the cost of production. This issue was investigated by T. Livoshko (2022), who justified the organisational and economic mechanism of energy saving, identified groups of measures (organisational, technological, investment), and emphasised the role of personnel motivation. The proposed solutions help to reduce costs and improve energy efficiency. However, the criteria for evaluating the effectiveness of measures have not been specified, and there is no mechanism for monitoring and considering regional specifics, which requires further analysis.

The purpose of this study was to develop effective approaches for optimal management of financial resources for the introduction of energy-saving technologies in the agricultural sector considering the specifics of the activities of agricultural enterprises. Within the framework of the study, the following tasks were set: to analyse the available sources of financing used for the implementation of energy-efficient measures in agricultural enterprises; to determine the criteria for the effectiveness of financing management.

MATERIALS AND METHODS

The research was conducted within the framework of applied economics and management in the period 2020-2024, using a comprehensive theoretical, analytical, and applied approach to studying the mechanisms of managing the financing of energy-efficient solutions in agricultural enterprises. The theoretical basis was formed using fundamental studies by contemporary researchers, in particular M. Mahmood *et al.* (2024), G.N. Yuan *et al.* (2022) and M. Adamowicz (2022). These studies were selected because of their significant contribution to the development of conceptual models for integrating environmental responsibility into financial management, and through the development of innovative strategies for improving energy efficiency in the agricultural sector, which corresponded to the topic and specifics of this study. The application of their approaches has provided a methodological basis for assessing financial processes in the context of current challenges to sustainable development. The analytical block included research on modern digital monitoring platforms, such as EOSDA Crop Monitoring (n.d.), Climate FieldView (n.d.), and Wexus Energy Management (n.d.). The choice of these platforms was conditioned by their wide functionality, ability to integrate various types of data, and application in the practice of agricultural production, which ensured the reliability and complexity of the analysis of energy consumption and the state of agricultural production.

As part of the organisational and economic analysis, the state programme "Affordable loans 5-7-9%" was studied (PrivatBank, n.d.), which was a key instrument of concessional lending to agricultural enterprises in 2024-2025. The study analysed statistical data on the number of attracted loans and financial activity of the agricultural sector in the context of this programme. Special attention was paid to the investigation of the role of international donors and grant programmes, including the Food and Agriculture Organization (FAO) in partnership with the European Union (State Agricultural Register, 2025), the United States Agency for International Development (USAID) (ACREC, n.d.), and the programme Ukraine – Local Empowerment, Accountability and Development "U-LEAD" (Decentralisation, 2024). The inclusion of these international initiatives allowed for a comprehensive approach to financing energy efficiency projects, covering both state and donor support, creating favourable conditions for the implementation of innovative technologies. Special attention was paid to the use of digital systems for monitoring financial flows and reporting, which contributed to increasing transparency and optimising management processes (Ministry of Education and Science of Ukraine, 2024). The practical aspect of the study was based on a comprehensive analysis of financial mechanisms and management decisions of agricultural enterprises on the example of the agricultural holding Myronivskyi Hlibproduct (MHP). Research of MHP activities, in particular the implementation of biogas complexes Biogas Ladyzhyn (Ecobusiness, 2021) and Oril-Lider" (Ukrainian Energy, 2021; MHP, n.d.a), provided an opportunity to comprehensively assess the existing mechanisms for financing energy-efficient projects.

RESULTS AND DISCUSSION

Theoretical and methodological foundations of financing management for energy-efficient solutions

Energy-efficient technologies in agriculture play a key role in reducing energy consumption, increasing productivity, and minimising negative environmental impacts. Their implementation is a response to contemporary challenges related to energy security, rising energy prices, and the need for sustainable development of agricultural production. In general terms, energy-efficient technologies are a set of technical, organisational, and managerial decisions aimed at reducing energy costs without lowering production volumes or deterioration of product quality. Their application in agriculture covers a wide range of processes – from soil preparation to storage and processing of agricultural products (Fu & Niu, 2023).

In the practice of agricultural enterprises, energy-efficient technologies are classified according to several criteria. According to their functional purpose, technologies are distinguished that ensure efficient use of energy in the processes of tillage, sowing, irrigation, harvesting, transportation, drying, cooling, lighting, and heating of livestock premises. According to the sources of energy saving, technologies are divided into passive and active. Passive technologies include solutions that reduce energy losses – thermal insulation of warehouses, ventilation systems with heat recovery, and the use of natural light. Active technologies replace conventional energy sources with alternative ones or optimise consumption: installation of solar panels, biogas plants, wind turbines, and the introduction of intelligent energy management systems (smart metering, FMS systems) (Yuan *et al*., 2022).

According to the energy source, technologies are divided into those that run on fossil fuels with high efficiency factor, and those that use renewable sources. The use of the latter is especially relevant for farms and enterprises that have their own raw materials for energy production – for example, organic waste that is processed into biogas. In the context of digitalisation, energy efficiency information technologies are distinguished separately – monitoring platforms, sensor systems, automated solutions based on artificial intelligence (AI), which allow predicting energy costs and optimising equipment operation modes. Examples of such solutions are EOSDA Crop Monitoring (n.d.), which allows tracking the state of crops on satellite images, determine vegetation indices (Normalised Difference Vegetation Index (NDVI), Modified Soil-Adjusted Vegetation Index (MSAVI)), predicting yields, and estimating the need for resources for each site. This helps to reduce the cost

of fertilisers, plant protection products and fuel, and improve the accuracy of agricultural production solutions. Internet of Things (IoT)-platforms like Climate FieldView (n.d.) combine data from field sensors, tractors, combine harvesters, weather stations, and satellites. Due to this, farmers receive an adaptive tool for managing sowing, fertilising, irrigation, and harvesting. In particular, PJSC Zernoprodukt MHP (MHP, n.d.b) began implementing Climate FieldView as part of the MHP Digital Farming project. During the training organised by the platform's specialists, agronomists, engineers, and combine harvesters were demonstrated the possibilities of crop mapping and field analysis. Based on the results of working with the programme, it was noted that accurate identification of problem areas, regulation of the technology of sowing, fertilisation, and harvesting allows minimising crop losses, increasing labour productivity and profitability of the farm. The use of this platform also helps to optimise fuel costs, reduce unproductive processing and form an effective economic strategy of the enterprise (AgroTimes, 2022). Another example is Wexus Energy Management (n.d.) – a service for monitoring electricity consumption on farms in real time. The system allows detecting inefficient use of equipment, manage energy loads, and optimise costs. According to the developers, its use in medium-sized farms allows achieving annual savings of 20-30% of the cost of electricity. The introduction of such technologies allows agricultural enterprises to make informed financial decisions regarding the modernisation of equipment and reduction of energy costs. A significant advantage of introducing energy-efficient technologies in agriculture is not only saving energy resources, but also reducing the cost of production, increasing competitiveness and compliance with environmental standards, which opens up access to new markets (Mahmood *et al*., 2024).

Managing financial resources in a transition to sustainable development involves a strategic rethinking of traditional financial models considering environmental, social, and economic challenges. At the centre of theoretical approaches is the concept of Sustainable Development, which provides for meeting the needs of the modern generation without compromising the opportunities of the future. With this in mind, the financial policy of an agricultural enterprise should be aimed not only at maximising profits, but also at minimising environmental impact, conserving resources, and improving energy efficiency. Contemporary scientific approaches require the inclusion of elements such as environmental budgeting, integrated risk management, long-term forecasting and cost assessment of energy innovations (Viles *et al*., 2022).

One of the key theoretical provisions is the introduction of the principles of the green economy, according to which investments are directed to projects with high energy-saving potential, the development of renewable energy sources, and the modernisation of fixed assets. Examples of such projects are the construction of biogas plants at agricultural enterprises, the installation of solar panels on farms (for example, Solar Farm Solectra (n.d. in the Vinnytsia Oblast), modernisation of irrigation systems using energy-efficient pumps, and the introduction of energy-saving drying complexes in the grain processing industry. In particular, biogas plants allowed agricultural producers to dispose of organic waste and obtain biogas for generating electricity and heat, reducing the consumption of conventional resources such as gas or coal. The introduction of such technologies has reduced CO_2 emissions by thousands of tonnes annually, increasing the energy autonomy of enterprises. The Dobrivlyany photovoltaic power plant (PVPP) has a capacity of 7 MW, covers an area of 9 hectares, and has over 16,000 solar modules, with a total investment of UAH 158 million (Samosvat, 2019). As of the beginning of 2022, the total installed capacity of solar power plants in Ukraine exceeded 6.4 GW, and the share of domestic power plants – more than 1.2 GW, which provided approximately 1.4 billion kWh of green electricity per year and covered the needs of 460 thousand households. This has helped to reduce the burden on the centralised energy system, increase the stability of energy supply for agricultural enterprises, and reduce dependence on unstable supplies of conventional resources (Chayka, 2023). Despite the significant potential, the amount of budget financing through the Decarbonisation

Fund of Ukraine in 2024 amounted to only about UAH 1.4 billion, which is insufficient for a complete transformation of the industry, while the total investment potential of the energy efficiency sector was estimated at more than EUR 50 billion (Ukranian Energy, 2024). Such initiatives not only contribute to reducing the consumption of traditional energy resources, but also ensure the stability of production in the face of rising tariffs and environmental challenges. In this context, management decisions should be based on the principles of environmental feasibility and economic efficiency. The theory of sustainable finance also emphasises the importance of considering external effects – both positive and negative – when assessing the feasibility of certain expenditures. This requires advanced financial analysis that goes beyond conventional profitability indicators and covers the impact on the environment, employee health, local communities, etc. (Adamowicz, 2022).

A special place in the theory is occupied by the concept of ESG factors (Environmental, Social, Governance), which is increasingly being implemented in the practice of strategic planning. These factors allow building the financial model of an enterprise in such a way that it is attractive to investors who focus on social responsibility and long-term sustainability. In agriculture, where a significant part of the costs is related to energy needs, financing should also consider the possibility of attracting green loans, participation in energy modernisation programmes, climate grants, and tax benefits for the use of energy-saving technologies. In addition, theoretical models focus on the need to create an adaptive financial management system that can quickly respond to changes in the regulatory field, energy prices, climatic conditions, or geopolitical situation. In particular, the concept of financial stability provides for the availability of reserve funds, access to insurance instruments, and a dynamic cost structure, which allows the enterprise to maintain economic balance even in conditions of instability (Huang, 2024).

The methodology for assessing the financial effectiveness of implementing green solutions involves combining conventional financial instruments considering the social and environmental consequences of projects. Unlike conventional investments, eco-oriented initiatives require an integrated approach to valuation, where long-term effects on society and the environment play an important role along with profitability. The methodology is based on formal financial indicators, such as net present value (NPV), which allows estimating the total benefit of a project based on the cost of money over time. This criterion is the basic one for determining the economic feasibility of environmental investments. Another key indicator is the internal rate of return (IRR), which shows the level of return on investment regardless of the cost of capital. It is especially important in the case of green projects, because such investments often have a high initial cost threshold, but simultaneously generate long-term benefits. The benefit-cost ratio (BCR) is also used, which allows comparing the presented benefits with expenses, the discounted payback period (DPP) to consider the time factor of return on funds, the return on investment index (RI), and the simple payback period (PP), which allows estimating the rate of return on invested funds. In addition, the methodology takes into consideration the efficiency of using the financial resources of the enterprise implementing the project. These indicators include the return on capital, assets, and sales, which allows assessing how effectively the company generates profit in the context of attracted resources. Liquidity and solvency are also considered, which indicate the company's ability to meet its financial obligations in the short and long term. The equity concentration coefficient, in turn, allows assessing the financial stability of the enterprise. An important component is the assessment of economic, social, and environmental consequences. Energy savings, reduction of harmful emissions, positive impact on public health and possible growth in employment are considered. It also analyses the impact of project implementation on the value of assets and changes in market conditions. The methodology provides for the inclusion of informal criteria such as the country's investment attractiveness, the level of competence of management personnel, and the availability of the necessary infrastructure (Olayinka, 2022). All cash flows are brought to the present value, which ensures an adequate

reflection of the opportunity cost of capital. A mandatory step is to analyse the risks that may affect financial results, and assess the effect of the project for interested parties – the community, employees, and authorities. Based on this integrated approach, the methodology allows not only measuring profitability, but also assessing the project's compliance with the principles of sustainable development.

Instead, research by P.D. Long *et al.* (2024) covered a broader context and proposed six groups of financial mechanisms, including public, private, market and innovation financing, risk reduction tools, and institutional support. The researchers showed how these tools were applied at different stages of the energy transition – from initiation to a sustainable future. In contrast, this study did not form a step-by-step model, but focused on applied aspects and identifying barriers to financing in the agricultural sector. C. Herce *et al.* (2024a) analysed financial incentives in terms of their integration into European sustainable development policies, which included evaluating the effectiveness of tax incentives and regulatory practices at the macro level. In contrast to this systematic approach, the current study focused on the micro level – the problems of access to finance for small and medium-sized agricultural enterprises in Ukraine. Despite this, both studies suggested that financial support is a key condition for a successful energy transition.

The study by T.A. Jensen *et al.* (2024) proposed an analytical model for optimising energy consumption based on digital platforms and geographic information systems. It also provided an assessment of the socio-economic impact of such measures in agriculture. But the current study focused on practical problems of lending, state support, and other sources of financing that are relevant for Ukrainian farmers. Although both approaches differ in methodology, they equally emphasise the role of financial factors in ensuring energy efficiency. Comparing this paper with the study by A. Ur Rehman *et al.* (2024), both noted the importance of energy efficiency for the agricultural sector and the presence of financial barriers. The study by A. Ur Rehman focused on technical solutions and sources of energy consumption on farms in South Asia, while the current study focused on financial mechanisms for supporting energy efficiency in the Ukrainian agricultural sector. Thus, both approaches complement each other-technical and managerial.

The introduction of energy-efficient technologies in agriculture is an important tool for improving the resource and financial stability of agricultural enterprises. This allows not only reducing energy costs and production costs, but also adapting to modern challenges of sustainable development and climate change. A comprehensive financial assessment of such projects should include both economic and socio-environmental aspects, which ensures informed management decision-making. Thus, energy efficiency combined with innovative financial approaches is a key factor in the modernisation of the agricultural sector.

Organisational and economic aspects of managing the financing of energy efficient measures

The structure and sources of financing of energy-efficient solutions at agricultural enterprises in Ukraine is a multicomponent system based on a combination of domestic resources, bank lending, state support, and international technical assistance. Agricultural enterprises are increasingly investing in the modernisation of production facilities, the introduction of green technologies, renewable energy sources, and digital monitoring systems, which reduces energy costs, increases competitiveness, and meets the requirements of sustainable development. The main external source of financing for farmers remains bank lending. Agricultural enterprises received significant support under the programme "Affordable loans 5-7-9%" (PrivatBank, n.d.), which provides for preferential conditions. In 2024, 8,750 agricultural enterprises attracted UAH 46.9 billion under this programme. In total, in 2024, 13,088 agricultural farms used bank loans totalling UAH 104.5 billion, which indicates a high activity of the agricultural sector in the credit market (Ministry of Agricultural Policy and Food of Ukraine, 2024).

During 2025, more than 3,251 agricultural enterprises have already attracted UAH 19.1 billion, which confirms the growing demand for

affordable financing of modernisation projects. Agricultural enterprises also actively use their own funds to upgrade their technical fleet, purchase generators, solar panels, heat pumps, etc. In 2025, more than UAH 18 billion was provided for state support programmes for the agricultural sector, of which a significant part was allocated to compensate for interest rates on loans. In addition, the government has expanded the programme "Affordable loans 5-7-9%" to finance the purchase of energy generation systems from renewable sources. The amount of such a loan can reach up to UAH 150 million with a term of up to 10 years (Pavlenko, 2025). International organisations actively finance projects in the field of energy efficiency in the agricultural sector, providing both grant and technical support, in particular through targeted programmes. The most significant ones are shown in Table 1.

Table 1. Main international donors and areas of financing energy-efficient projects in the agricultural sector of Ukraine for 2024

Organisation	Amount of grants / support	Main areas of financing
FAO + EU	USD 2.8 million	Green technologies, infrastructure
USAID	USD 37 million	Biofuels, energy efficiency
GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit), U-LEAD programme	USD 40 million	Energy efficiency in communities
EU	up to EUR 1.5 million	RES, technical and economic feasibility studies

Source: compiled by authors based on Decentralisation (2024), Sluga narodu (2025), State Agricultural Register (2025)

FAO has already provided support to 237 agricultural producers in Western Ukraine, which has contributed to the introduction of energy-saving technologies. USAID (ACREC, n.d.) and GIZ also implement a number of programmes that include the purchase of energy-efficient equipment, infrastructure development, and support for local communities. In particular, GIZ has a Power Up! project, which provides grants to Ukrainian enterprises for the purchase of energy-efficient equipment. Priority is given to enterprises affected by the war in Sumy, Kharkiv, and Chernihiv oblasts starting in 2023 (East Europe Foundation, 2023). Simultaneously, USAID (Energy Security Project) ESP organises training events and provides cogeneration plants to heating companies in 19 cities of Ukraine, which will provide heat to more than 600 thousand residents. The programme also contributes to improving the legal and regulatory framework for the effective use of such installations (Murdza, 2025). For the period 2021-2024, the volume of investments in renewable energy (solar panels, bioenergy, wind generators) in the agricultural sector amounted to approximately EUR 200-400 million (State Agricultural Register, 2025). In particular, in 2022-2023, more than 650 MW of new capacities were commissioned in Ukraine, of which 371 MW were solar power plants, 227 MW were wind power, and 50 MW were bioenergy. This indicates a high rate of attracting investment, despite military and economic risks. Investments in solar power plants for farmers range from EUR 800-1,000 per 1 kW, and projects for 1 MW cost approximately EUR 700 thousand – 1 million. The cost of wind farms is EUR 1.2-1.5 million per 1 MW, and large projects can exceed EUR 75 million. The payback period for such projects is on average 5-10 years. The schedule of financing dynamics under the programme "Affordable loans 5-7-9%" shows a reduction in the volume of financing in 2024-2025 compared to the peak of 2022, but the number of attracted agricultural enterprises remains significant, which indicates the continued demand for soft loans even in times of crisis (Order of the Cabinet of Ministers of Ukraine No. 761-r, 2024).

Thus, the structure of financing energy-efficient solutions in the agricultural sector of Ukraine is formed based on a combination of domestic funds, bank loans, and international

support. The state programme "Affordable loans 5-7-9%" plays a key role in farmers' access to financing, in particular, in the field of energy efficiency. The FAO, USAID, and GIZ donor programmes also play a significant role, which help to reduce financial barriers for small and medium-sized farms. In particular, the FAO, in partnership with the European Union, implements a programme to support agricultural producers in the Western regions of Ukraine, which provides funding for the purchase of energy-efficient equipment, infrastructure modernisation, and the development of value chains. The USAID "Agro" programme provides technical and financial support to agricultural enterprises in implementing bioenergy solutions, implementing sustainable production standards, and improving market access. GIZ, within the framework of the "U-LEAD with Europe" initiative, finances projects to improve energy efficiency in communities, including the creation of municipal energy plans, the installation of solar panels for agricultural enterprises and the implementation of educational activities on energy management. Based on such programmes, farmers get the opportunity to modernise their production facilities with less financial risks. The increase in investment in renewable energy sources (RES) indicates a change in the paradigm of agricultural sector development towards sustainability, energy independence, and economic adaptability to new challenges.

Financial flow management in the implementation of green technologies in the agricultural sector of Ukraine is based on the integration of advanced information systems, international accounting standards, and cost efficiency monitoring tools. Enterprise Resource Planning (ERP) and Customer Relationship Management (CRM) systems provide automation of accounting and management accounting, increasing the transparency of financial statements, and making informed investment decisions. The most common ERP system among agricultural enterprises is 1C due to its wide functionality and availability. Integrated ERP systems, CRM, and accounting according to International Financial Reporting Standards (IFRS) are actively used mainly among medium and large agricultural enterprises (15-25% of the total number), which allows effectively managing business processes, in particular, in terms of energy-efficient projects (Ministry of Education and Science of Ukraine, 2024).

Integration of ERP and CRM systems with the requirements of International Financial Reporting Standards (IFRS) is accompanied by a number of challenges, in particular, the need to adapt software to reporting standards, provide qualified personnel, and technical integration with other management platforms. The implementation of such systems helps to improve accounting accuracy, reduce the level of financial risks, and also provides the basis for strategic planning and reporting on sustainable development. The level of transparency of reporting in the use of energy-efficient budgets in the agricultural sector is gradually increasing, but it remains insufficiently detailed. Companies covered by the Law of Ukraine No. 2258-VIII (2017) are required to provide open reporting, including on environmental initiatives. However, the detail of data on spending on green projects differs significantly depending on the size of the enterprise, industry, and domestic policy. Elements of non-financial reporting, including energy efficiency indicators, are gradually being integrated into the internal documentation of enterprises, although systematic monitoring and public disclosure of such data is a common practice. Stimulating factors are International Reporting Standards (IFRS, Global Reporting Initiative (GRI)), investor requirements, and government initiatives to achieve the sustainable development goals (Transparency Report..., 2024). In 2021-2024, agricultural enterprises actively implemented energy-efficient solutions with the support of international donors, which contributed to the modernisation of production (Ukrinform, 2024). Significant investment in renewable energy has been combined with digitalisation of accounting and management. Enterprises have implemented ERP, CRM, and IFRS, gradually integrating non-financial reporting, in particular energy efficiency indicators. This formed the basis for increasing the transparency and sustainability of the agricultural sector.

The level of transparency of reporting directly affected the effectiveness of implementing energy-efficient initiatives in the agricultural sector. Clear cost accounting, monitoring

of results and compliance with international standards ensured the trust of donors and investors. It was due to well-established reporting systems that enterprises more effectively attracted financing and implemented advanced technologies. This has become an important factor in the successful modernisation of agricultural production in conditions of limited resources. The actual costs of implementing energy-saving projects in the agricultural sector often differ from the planned ones by 10-20%, which is conditioned by the seasonality of agricultural work, fluctuations in prices for agricultural equipment, the need to adapt technical solutions to rural conditions, and the cost of additional work. In complex projects, such as the construction of biogas complexes or the installation of energy monitoring systems, cost deviations can reach 25%. The duration of the budget cycle for the implementation of energy-efficient initiatives at agricultural enterprises includes several stages: approval of funds lasts from 1 to 3 months, transfer – from 1 to 2 months after approval, and direct development – from 6 to 12 months, depending on the scale and seasonality of work. Thus, the full implementation cycle of an energy-saving project lasts on average from 8 months to a year (Resolution of the Cabinet of Ministers of Ukraine No. 485, 2025). Since 2024, there has been an updated procedure for using Decarbonisation Fund resources, which provides more transparent and standardised procedures, but there is still a risk of delays due to bureaucratic restrictions, tender requirements, and technical complexity of implementation. Centralised financing mechanisms, in particular, the Energy Efficiency Fund and the Decarbonisation Fund, provide 70-80% of the volume of state funding (Strategy of the state Institution..., 2023). Decentralised mechanisms (territorial communities, agricultural clusters, associations) implement 20-30% of funding, mainly through grant programmes, local initiatives, and co-financing. Their role is growing against the backdrop of increased international technical assistance and private capital participation (Energy transition, 2025).

S.T. Ijaz & S. Chughtai (2022) focused on the need to transform green economy policies, particularly in the context of Pakistan. Both papers emphasised the key role of the state in overcoming financial barriers and creating a favourable environment for implementing energy-efficient solutions. However, if S.T. Ijaz & S. Chughtai focused on the institutional and political plane, this study focused on direct instruments – financial programmes, grants, and loans, considering the local specifics of the agricultural sector in Ukraine. The study by E. Szafranko (2021) proposed a multidimensional analysis of energy efficiency financing systems, emphasising the relationship between institutional quality, public policy, and economic security. These elements were also partially present in this study. However, in contrast to the analytical and evaluation approach by E. Szafranko, the use of country ranking models was dominated by practical analysis – focused on barriers to access to finance and the search for applied solutions for the agricultural sector.

X. Liu *et al.* (2023) paid special attention to the potential of digital technologies to improve energy efficiency, including Big Data and artificial intelligence tools. Common to this study was an understanding of the importance of financial support and institutional stability. However, X. Liu *et al.* placed the emphasis on technological transformation as a driver of efficiency, while this study considered financial accessibility as a priority condition for change, focusing on the problems of small enterprises in the agricultural sector. In the publication by J. Chen *et al.* (2024), the main subject of the analysis was the impact of energy efficiency on access to finance among small and medium-sized enterprises in the UK. The study combined empirical data with analysis of the green bond market and ESG financial standards. Although both studies focused on the relationship between energy efficiency and funding, J. Chen *et al.* highlighted credit capacity of enterprises and institutional trust, while this study was dominated by the analysis of systemic barriers to financing the Ukrainian agricultural sector.

Financing of energy-efficient solutions in the agricultural sector of Ukraine is characterised by multicomponent nature, combining bank loans, enterprises' own funds, state support, and international technical assistance. The "Affordable loans 5-7-9%" programme remains a key tool for raising funds, especially for the

modernisation of production and the introduction of renewable energy sources. Simultaneously, the role of ERP, CRM systems, and IFRS in increasing the transparency of financial flow management is growing. In general, there is a change in the paradigm of agricultural production towards sustainability, energy independence and digital transformation.

Practical aspects of applying financial mechanisms and management decisions

Myronivskyi Hlibproduct agro-industrial holding actively implements energy-efficient technologies in its production activities, combining economic feasibility with environmental responsibility. One of the most ambitious examples is the biogas complex Biogas Ladyzhyn (Ecobusiness, 2019), located in the Vinnytsia region. The project was implemented in two stages, each of which had a capacity of 12 MW (MHP, n.d.a). The first stage, launched in December 2019, allowed providing electricity to more than 35,000 households annually and covered approximately 40% of the energy consumption needs of the MHP agroindustrial cluster. The construction costs of the complex were financed by equity, bank loans, and international technical assistance, in particular, through grant programmes to support green energy (Ekonomichna pravda, 2019).

From the standpoint of economic efficiency, the return on investment primarily in the biogas complex was approximately 7-8 years. This was due to revenues from the sale of electricity at the "green tariff" (0.15 EUR/kWh) and savings on external energy purchases. In addition, due to the processing of waste into biogas and the production of organic fertilisers, the company receives additional benefits, reducing the cost of mineral fertilisers. Its own fertiliser production allowed the company to increase the agrochemical efficiency of soils, and reduce its dependence on fluctuations in prices for imported raw materials. Environmental safety was ensured through a closed cycle of waste use, which significantly reduced the anthropogenic burden on the environment (Ukranian Energy, 2025).

The second Oril-Lider biogas complex, launched in 2013 in the Dnipropetrovsk region, has a capacity of 5 MW. Its operation ensured stable energy supply to production facilities and reduced energy costs by more than 30%. Due to stable electricity production, the company can also avoid peak tariffs for external consumption, which improves the overall cost balance and ensures predictability of energy costs (Ukrainian Energy, 2021). Both complexes together allow reducing CO_2 emissions by more than 100 thousand tonnes annually, which contributes to the achievement of the company's climate goals, and meets the requirements of ESG strategies and sustainable development standards (Ekonomichna pravda, 2019).

Cost-effectiveness management for implementing energy-efficient solutions is carried out using ERP systems, which allow monitoring costs in real time, generating analytical reports, and evaluating the economic feasibility of solutions. The introduction of digital resource accounting allows identifying energy losses in a timely manner and predicting the need for equipment modernisation. MHP also applies an internal approach to estimating the IRR (Internal Rate of Return), which in the case of bioenergy projects ranges from 14-17% over the horizon of 10 years. The cost of implementing such technologies, according to the company, has an average return on investment (ROI) of more than 12%, which is a high indicator for the agricultural sector, where typical investments have a lower margin (Pikalo, 2025).

In addition to power generating facilities, MHP invests in energy monitoring systems, lighting modernisation, and engine and pump upgrades at its enterprises. For example, the company's enterprises are switching to Light Emitting Diode (LED) lighting, which has reduced energy consumption for lighting by more than 60%. The installation of frequency converters on pumps and fans provided additional energy savings. All projects are subject to a preliminary feasibility study with determination of the level of energy saving and return on investment, which ensures transparency of the investment process and allows management to make informed decisions (MHP – Hromadi, n.d.).

In order to reduce the financial burden, MHP attracts external sources of support. The company cooperates with international partners, such as the European Bank for Reconstruction and Development (EBRD), and also uses state support

tools within the framework of programmes that encourage the introduction of green technologies. In 2023, MHP became one of the recipients of grant funding for the development of the biomethane sector, including the production of compressed biomethane for domestic needs and for export. According to the company, further expansion of bioenergy projects will allow MHP not only to reduce its dependence on traditional energy sources, but also to export excess energy to EU countries, which opens up new markets and sources of income (Pikalo, 2025).

Thus, the MHP example demonstrates an integrated approach to the introduction of energy – efficient technologies, where costs are carefully planned, calculated using advanced financial methods, and the achieved effect is measured not only through resource savings, but also through environmental benefits. Integration of digital management systems, accurate calculation of return on investment, and attraction of grant and credit resources form a management model that is appropriate for scaling in the agricultural sector of Ukraine. This experience shows the possibility of combining profitability with social and environmental responsibility, which meets requirements for sustainable development.

In the current conditions of energy uncertainty and rising cost of resources, agricultural enterprises should implement systematic approaches to improving energy efficiency. Despite the significant achievements of MHP agricultural holding in the field of energy-saving technologies, further improvement of management and investment in this area is necessary to achieve long-term economic and environmental sustainability. Key areas of improvement include four components: financial management, investment planning, digital technology adoption, and integrating sustainability into the company's strategy. It is advisable to expand the practice of independent energy audit with the subsequent development of a map of energy losses of the enterprise. This will allow distributing investments more efficiently, focusing them on areas with the highest savings potential. It is necessary to actively use green financing mechanisms, in particular international assistance programmes, issuing green bonds, and attracting concessional lending for renewable energy projects. Digitalisation of energy monitoring processes is an important area. Installation of intelligent sensor systems, integration of Supervisory Control and Data Acquisition (SCADA) solutions and automated energy management systems based on ERP will allow real-time detection of irrational energy use. Additionally, it is recommended to develop internal analytical expertise to assess IRR, NPV, and other project performance indicators, which will improve the quality of decision-making. Table 2 provides specific recommendations for improving the efficiency of implementing energy-efficient technologies in the activities of agricultural enterprises.

Table 2. Recommendations for improving the efficiency of implementing energy-efficient technologies in agricultural enterprises

Area	Recommendation	Expected result
Financial management	Introduction of an independent energy audit with a frequency of once every 3 years	Detection of areas of excessive power consumption
Investment planning	Development of domestic green investment policy; use of green bonds	Diversification of funding sources
Technological update	Installation of intelligent energy metering systems, modernisation of LED lighting	Reduction of energy costs by up to 25%
Analytics and performance evaluation	Internal calculation of ROI, NPV, IRR for each project	Making informed investment decisions
State interaction	Increased participation in the programmes "Affordable loans 5-7-9%", FAO, USAID, EU grants	Increase in external financing
Educational initiatives	Advanced training of energy managers and economists of the enterprise	Strengthening of energy management competencies
ESG integration	Inclusion of sustainability indicators in corporate reporting	Improving of reputation and access to international investment

Source: compiled by the authors based on Ekonomichna pravda (2019), State Agricultural Register (2025), MHP – Hromadi (n.d.)

The application of the proposed solutions will not only increase the energy efficiency of the enterprise, but also reduce CO_2 emissions, optimise the cost structure, and ensure greater resistance to external risks – economic, energy, regulatory. The expansion of the portfolio of energy-saving projects at MHP should be accompanied by transparent monitoring of the results achieved, which meets international management standards. Thus, the energy efficiency management system should be considered as a strategic asset of the enterprise and the basis for long-term growth.

Comparing this study with paper by A. Chughtai *et al.* (2024), a general recognition of the role of financial instruments and institutional support in improving energy efficiency in developing countries can be noted. Both studies highlighted the importance of concessional lending, partnerships, and a strategic approach to investment. A. Chughtai *et al.* considered this issue in the global context of sustainable development and green financing, while this study focused on applied barriers and financial mechanisms of the agricultural sector of Ukraine.

In the case of A. Kerstens & A. Greco (2023), a general understanding of the importance of funding to support energy efficiency was observed, but the difference was in application levels: A. Kerstens & A. Greco investigated urban areas and communities, and this study considered individual agricultural enterprises. They focused on socio-organisational barriers and the need for political change, while here the main focus was on practical financial difficulties and ways to overcome them. Both approaches complemented each other, combining the system and practical levels. M. Economidou *et al.* (2024) highlighted the role of financing energy-efficient projects in regional initiatives in Europe, especially in the field of buildings, with a focus on local authorities and European foundations. The current study focused on the agricultural sector of Ukraine and relevant national loan programmes and grants. While both approaches recognised the need to overcome financial and technical barriers, the scope and scale were different. Thus, M. Economidou *et al*. provided a systematic review of EU policies, and this study represented a practical analysis of local challenges and mechanisms.

Comparison with B. Wepner *et al.* (2025) found that both studies recognised the importance of stakeholder engagement and an integrated approach to sustainable agricultural development. However, B. Wepner *et al.* paid more attention to the technological, cultural, and political aspects of digital transformation of sustainable agri-food systems, while the current study focused on financial barriers and practical solutions to improve energy efficiency. Such approaches complemented each other, revealing both technological and financial aspects. Compared to C. Herce *et al.* (2024b), both studies recognised the importance of energy consumption analysis for developing effective policies. C. Herce *et al.* focused on methodologies for data collection and correction for SMEs in different EU countries, while this study focused on local financial mechanisms and support programmes in the agricultural sector of Ukraine. Thus, C. Negse *et al.* proposed a scientific and methodological basis, and this research is a practical tool for implementing energy efficiency.

The introduction of energy-efficient technologies has helped to lower energy consumption, reduce costs, and improve environmental safety. The use of advanced bioenergy complexes, digital monitoring, and automation systems allowed increasing the productivity and efficiency of energy resource management. Effective financing and attracting state and international support played a key role in the implementation of such projects. In general, the integration of economic feasibility and environmental responsibility became the basis for sustainable development of the agricultural sector.

CONCLUSIONS

This study showed that the introduction of energy-efficient technologies at agricultural enterprises in Ukraine is an important factor in improving competitiveness, environmental safety, and sustainable development of the agricultural sector. Analysis of financial mechanisms has shown that the structure of financing energy-saving measures is formed by combining internal resources of enterprises, bank loans, state support, and international technical assistance. In particular, the state programme "Affordable loans 5-7-9%" plays a key role in ensuring farmers'

access to concessional financing, because in 2024 this program attracted UAH 46.9 billion of loans to 8,750 enterprises, and the total amount of bank lending to the agricultural sector amounted to more than UAH 104.5 billion. This indicates a high level of activity of farmers in the credit market, despite economic challenges.

International donors, including FAO, USAID, GIZ, and the EU, have provided significant support in the form of grants and technical assistance worth tens of millions of USD aimed at developing green technologies and renewable energy. As a result, during the period 2021-2024, investments in renewable energy sources in the agricultural sector reached EUR 200-400 million, and the commissioned capacities in 2022-2023 amounted to more than 650 MW, including 371 MW of solar power plants, 227 MW of wind, and 50 MW of bioenergy complexes. This indicates a gradual change in the paradigm of agricultural production towards sustainability and energy independence.

Using the example of MHP agricultural holding, the effectiveness of an integrated approach to energy efficiency is demonstrated, which combines its own investments, bank lending, and international support. The Biogas Ladyzhyn complex with a capacity of 24 MW annually provides electricity to more than 35,000 households, covering about 40% of the needs of the agroindustrial cluster, and the payback period of the project is estimated at 7-8 years. The use of digital monitoring systems, ERP, and CRM increases the transparency of financial flow management and allows optimising costs. In addition, the introduction of LED lighting and frequency converters has reduced energy consumption by more than 60%, which significantly reduces operating costs.

It is important to note that effective financial management in the field of energy efficiency requires not only raising funds, but also developing a domestic green investment policy, regular energy audits, analytical assessment of project profitability (ROI, IRR, NPV), and integrating ESG factors into the corporate strategy. The implementation of these recommendations will help to increase the financial stability of enterprises, diversify sources of financing, and reduce the environmental burden. A limitation of this study is to focus mainly on the financial mechanisms and practices of the agricultural sector of Ukraine without an in-depth analysis of the technical aspects of implementing energy-efficient technologies. The prospect of future research is a comprehensive study of the impact of digital technologies and artificial intelligence on improving energy efficiency and integrating innovative financial instruments to support the sustainable development of the agricultural sector.

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Механізми управління фінансуванням енергоефективних рішень на аграрних підприємствах

Анотація. Метою даного дослідження було встановити підходи до раціонального використання фінансових ресурсів для впровадження енергоощадних технологій в аграрному виробництві з урахуванням особливостей функціонування підприємств у сільському господарстві. У ході дослідження було проведено комплексний теоретичний і аналітичний аналіз механізмів фінансування енергоефективних заходів, оцінено доступність різних видів фінансової підтримки та критерії ефективності управління фінансами. Особливу увагу приділено аналізу державної програми «Доступні кредити 5-7-9 %», за якою у 2024 році аграрні підприємства отримали 46,9 млрд грн кредитів, залучивши 8 750 учасників, а загальний обсяг банківського кредитування агросектору склав понад 104,5 млрд грн. Вивчено також роль міжнародних донорів і грантових програм, зокрема підтримку від Food and Agriculture Organization у партнерстві з Європейським Союзом, United States Agency for International Development, та програму Ukraine – Local Empowerment, Accountability and Development, які сприяли розвитку енергоефективних проєктів у агросекторі. Практична частина дослідження базувалася на аналізі фінансових механізмів і управлінських рішень агрохолдингу «Миронівський хлібопродукт», зокрема щодо реалізації біогазових комплексів «Біогаз Ладижин» та «Оріль-Лідер», що дозволило всебічно оцінити діючі моделі фінансування. Біогазовий комплекс «Біогаз Ладижин» потужністю 24 МВт забезпечував електроенергією понад 35 000 домогосподарств щороку, задовольняючи близько 40 % потреб агроіндустріального кластера, при цьому термін окупності проєкту становив 7-8 років. Отримані результати засвідчили, що поєднання внутрішніх ресурсів, банківських кредитів, державної підтримки та міжнародної допомоги створює ефективні умови для модернізації виробництва і впровадження інноваційних технологій. Практичне значення дослідження полягає у можливості використання його результатів для вдосконалення системи фінансування енергоефективних проєктів, підвищення ефективності управління ресурсами та підтримки сталого розвитку аграрного сектору в майбутньому

Ключові слова: інвестиції; біогаз; кредит; ресурс; модернізація