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Economic consequences of implementing sustainable energy consumption programmes in industrial companies

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Abstract. The aim of the study was to determine the impact of managerial and technological changes in energy use on the performance of industrial companies. The methodology was based on theoretical, empirical and comparative methods for analysing the effects of energy efficiency and sustainable energy consumption. The economic mechanisms of the impact of investments in energy efficiency were identified: reduction of specific energy costs and volatility of operating expenditure, increase in total factor productivity, and hedging of regulatory and price risks. It was emphasised that the effect is significantly enhanced by the availability of digital technologies (artificial intelligence-based energy management, predictive maintenance) and access to financing, while tight credit conditions remain a key barrier to the implementation of energy efficiency projects. It has been established that investments in energy efficiency reduce energy costs and risks, increase operational efficiency and competitiveness through modernisation and digitalisation, while limited financing and low digital maturity of enterprises remain the main obstacles. Metinvest Holding reduced its energy consumption to ≈ 8.2 billion kWh in 2024 and allocated USD 145 million to energy efficiency, Interpipe maintained the highest Earnings Before Interest, Taxes, Depreciation, and Amortisation margin of 34%, while ArcelorMittal invested ≈ USD 110 million in decarbonisation programmes. It has been found that in Ukraine, the share of renewable energy sources in production in 2024 is 8.7%, 17-18% in summer, 4-7% in winter, with profits for large/medium-sized enterprises at 776.4 → 947.3 billion UAH (+22%) and loss-making companies at ~22.1%. Ukrainian industry proved that even in crisis conditions, energy efficiency programmes ensure cost reduction, profit growth and increased sustainability of enterprises. It is advisable to implement comprehensive energy efficiency programmes – a combination of technical solutions, digital management systems and financial monitoring of savings. The results can be used by companies and government agencies to improve energy efficiency and develop sustainable energy consumption strategies, particularly in Ukraine

Keywords: profitability; optimisation; forecasting; resource efficiency; energy productivity; hedging

Introduction

Energy consumption in industry is becoming one of the main factors in sustainable development and competitiveness. Improving energy efficiency, transitioning to resource-saving technologies and minimising carbon footprints are not only environmental but also economic challenges. In the context of global energy challenges caused by stricter climate policies, rising energy prices, and the need to improve national energy security, the implementation of sustainable energy consumption programmes is seen as a strategic direction for industrial modernisation and a fundamental tool for long-term economic growth, including in Ukraine.

Scientific research confirms that the economic feasibility of energy modernisation of industrial enterprises is based on optimising the structure of energy consumption and adapting technological processes. A. Huang *et al*. (2025) proved that combining economic and environmental optimisation can reduce energy costs by 15-25% and cut specific CO_2 emissions, demonstrating the mutually reinforcing effect between energy efficiency and financial performance in production. This meant that investments in hybrid energy systems generate long-term economic benefits, increasing the competitiveness of the industrial sector even in conditions of energy instability. The study by T. Schmitt *et*

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al. (2025) contributed to the development of methods for improving energy efficiency by proving the effectiveness of simulation and optimisation approaches in industrial management. The authors found that such integration of optimisation models increases not only energy efficiency but also production productivity, providing a sustainable economic effect for enterprises.

J. Kim *et al.* (2024) emphasised that energy, material and resource efficiency should be considered comprehensively, as it is the synergy of technological innovations and socio-technical systems that ensures the maximum economic effect of industrial decarbonisation. Countries that implement policies to promote resource efficiency gain an additional 1.5% in gross domestic product (GDP) growth each year by reducing their dependence on imported energy and increasing domestic investment. This has shaped a systemic view of the link between energy strategy, industrial innovation and macroeconomic growth J. Andrijevskaja & A. Volkova (2025) summarised quantitative approaches to energy conservation assessment and showed that systematic management of energy consumption data improves the accuracy of forecasting and the rationality of investment decisions in the industrial sector. The use of combined indicators of energy intensity and economic performance allowed the authors to identify the most effective areas for modernising production processes, deepening the understanding of the relationship between analytical accounting of energy resources and improving the overall economic efficiency of enterprises.

One of the key aspects of the economic efficiency of energy modernisation is the identification of internal causes of irrational energy consumption and opportunities for its optimisation. The work of J. Ma (2024) focused on a cause-and-effect analysis of energy inefficiency and showed that management losses and ignoring dynamic consumption factors significantly reduce the economic return on investment in the modernisation of production systems. This approach highlighted the relationship between the quality of management decisions and the financial results of energy efficiency programmes. Increasing the flexibility of electricity consumption in industry as a factor in reducing costs and stabilising the energy balance was studied in a study by S. Rojas-Innocenti *et al.* (2025). The authors compared different configurations of industrial enterprises and found that the adaptability of electricity consumption systems allows for a reduction in peak loads and savings of up to 8-12% in energy costs, which directly affects the cost of production. The results confirm the economic feasibility of implementing flexible energy management systems as an effective tool for increasing the competitiveness of the industrial sector.

In the Ukrainian context, the issue of sustainable energy consumption is critical due to energy challenges caused by the war, rising energy prices, and the need to reduce import dependence. F. Mei *et al*. (2024) found that corporate social responsibility is one of the factors contributing to increased energy efficiency in Ukrainian industrial companies. The authors demonstrated a positive link between the level of corporate social responsibility and the reduction of specific energy consumption, indicating the potential synergy of socio-economic and technological instruments in the sustainable development of enterprises. A study by V. Horskyi (2025) revealed an increase in the efficiency of thermal energy consumption by Ukrainian industrial enterprises under environmental constraints and proved that the introduction of heat recovery technologies can reduce the energy intensity of products by up to 30%, increasing competitiveness in the European market. This revealed the economic potential of recovery technologies in Ukrainian industry and highlighted their importance for the implementation of a low-carbon development strategy for the national economy. U. Andrusiv *et al*. (2023) proved that systematic assessment and forecasting of fuel and energy resource use make it possible to optimise the structure of the national energy balance and reduce the financial burden on the industrial sector. The results obtained have deepened the understanding of the role of analytical forecasting in improving the effectiveness of Ukraine's energy policy and its ability to ensure sustainable economic growth under resource constraints.

However, despite the availability of research, there was a lack of comprehensive analysis of the economic consequences of implementing sustainable energy consumption programmes at the level of industrial companies, as most studies have a technical, technological or environmental focus. In the Ukrainian context, the issue of integrating energy efficiency into corporate strategies and financial planning of enterprises has been considered to a limited extent. There is also a need for further research on assessing the multiplier effect of energy modernisation, in particular its impact on employment, innovation activity and long-term profitability. Thus, the aim of the study was to substantiate the economic prerequisites and results of improving the energy efficiency of the industrial sector through the implementation of solutions aimed at optimising energy consumption and strengthening the competitiveness of enterprises. To achieve this aim, the relationship between the level of technological modernisation, digital maturity and financial indicators of enterprises in various industries in Ukraine was investigated, the economic effects and barriers to the implementation of rational energy consumption programmes were summarised, and the conditions for their impact on sustainable growth in efficiency and profitability were identified, with adaptation to the Ukrainian context.

Materials and Methods

The study covered a comprehensive approach that involved the use of analysis, comparison and generalisation methods to assess the economic effects of sustainable energy consumption, study the impact of energy modernisation and identify areas for adapting effective models to the conditions in Ukraine. Economic mechanisms were presented for the impact of investments in energy efficiency

(EE) on the performance of industrial enterprises, reducing operating expenditure (OPEX) (Amendola *et al*., 2024) and increasing total factor productivity (TFP) (Na *et al*., 2025). The effect of hedging price and regulatory risks (Dorigoni & Anzalone, 2024) and the role of digitalisation (Artificial Intelligence (AI), predictive maintenance) and financing as mediators of this relationship (Li *et al*. 2025) were considered. The main goal was to build a theoretical framework for the economic effect of EE and to form an analytical basis for further analysis. The effect of EE programmes on profitability was assessed using energy intensity indicators (kWh/t; GJ/t), specific energy costs in production costs (%), and financial metrics (EBITDA, margin). EBITDA elasticity with respect to energy intensity and a comparison of the "before/after" implementation of projects were used for interpretation.

Using the comparative analysis method, the energy and financial results of leading industrial companies in Ukraine – Metinvest Holding (2023), Interpipe (2023; 2024) and ArcelorMittal (2024) based on publicly available corporate reports for 2023-2024 (the analysis was based on data for 2023-2024 as the latest available and relevant). The companies' data covered various types of energy strategies (modernisation, digitalisation, decarbonisation), which made it possible to compare the effectiveness of different approaches to sustainable energy consumption in the Ukrainian context. For each enterprise, the following indicators were assessed: energy consumption, energy balance structure, energy costs, capital expenditure (CAPEX), profitability (Earnings Before Interest, Taxes, Depreciation, and Amortisation (EBITDA), margin, net profit) and implementation of energy efficiency programmes. The objective of this stage was to empirically verify the economic effect of sustainable energy consumption programmes at the level of individual enterprises and to confirm the correlation between energy modernisation, digitalisation, and financial results (profitability, return on investment, operational stability).

Using empirical methods of comparative and structural analysis, a quantitative assessment of the conditions for implementing sustainable energy consumption programmes was carried out. To this end, Ukraine's key energy and financial indicators for 2023-2024 were analysed based on official reports from BDO (2023) (Binder Dijker Otte), NERC (National Energy and Utilities Regulatory Commission of Ukraine) (2023) and the State Statistics Service of Ukraine (2025). Additional information for comparative analysis was obtained from reports by the International Energy Agency (2025), DiXi Group (2025a; 2025b), Energy Partnership Ukraine (2024) and Ember (2024). The selected criteria (installed capacity of RES (renewable energy sources), share of RES in electricity generation, volumes of "green" generation, investments in RES/ (Distributed Energy Resources (DER) and total corporate profits) represented the technical, structural, financial and performance components of energy development. They were selected due to the need to reflect both the resource base and the level of energy independence, as well as the economic effect of modernisation on the national economy. The objective of this stage was to determine the relationship between the dynamics of renewable energy development, investment activity and the financial results of industry, which made it possible to comprehensively assess the economic conditions of Ukraine's energy transition in 2023-2024. In addition, an analytical summary of the data obtained was carried out with the construction of comparative series and dynamic indicators for 2023-2024. This made it possible to track changes in the structure of the energy balance, investment activity and financial results of industrial enterprises. The relationship between the development of renewable energy sources, the share of RES in electricity production, the volume of investments in DER, and the aggregate profit of enterprises was assessed by comparing the growth rates of the relevant indicators. Based on these calculations, the economic mechanisms of the impact of energy efficiency programmes on the profitability and productivity of enterprises were determined.

Results and Discussion

In industry, investments in energy efficiency (EE) operate through three main mechanisms: the sustained reduction of specific energy costs and OPEX volatility, which directly supports profit margins and reduces the risk of cash gaps; the growth of operational efficiency (from reduced downtime and defects to optimised capacity utilisation), which increases total factor productivity (TFP) and enhances firms' ability to withstand price competition; and the strategic hedging of regulatory and price risks (carbon payments, tariffs), which helps stabilise cash flows and the cost of capital (Dorigoni & Anzalone, 2024; Romero-Jordán *et al*., 2025). The effect is significantly amplified when complemented by digitalisation (AI-based energy management, predictive maintenance), as algorithms enable additional savings from existing assets and accelerate the payback of modernisation projects (Li *et al*., 2025). A major constraint is access to finance: tight lending conditions lead to systemic underinvestment in EE projects even when they have a positive Net Present Value (NPV), delaying benefits for profitability and business resilience (Zhang *et al*., 2025).

At the business-model level, EE increases energy productivity (output per unit of energy consumed), which is transformed into higher factor productivity and competitiveness due to lower production costs and greater pricing flexibility. For energy-intensive industries (steelmaking, chemicals), this creates a long-term "profitability framework": the effect is not one-off but accumulates with each shift in the technological paradigm (Na *et al*., 2025; Romero-Jordán *et al*., 2025). However, potential diminishing returns must be considered (the most profitable measures are implemented first), as well as the rebound effect, where part of the savings is absorbed by increased production volumes. This creates the need for comprehensive portfolios of EE solutions and management practices that allow savings to be captured in companies' financial results (Amendola *et al.*, 2024).

The practical implementation of these approaches covers the following areas: equipment modernisation – targeted replacement or retrofitting of components with high energy profiles (furnaces, compressors, drives, heat exchangers) aimed at reducing specific energy consumption and maintenance costs; in metallurgical processes this includes heat recovery, optimisation of blast parameters/calcination and electrification of selected stages (Na *et al.*, 2025); energy-efficient technologies – technical and digital solutions enabling the same production output with lower energy use: variable-speed drives, heat recovery, high-efficiency burners, VSD pumps, as well as AI-based dispatching systems and predictive maintenance, which reduce peak loads and downtime (Li *et al.*, 2025); and resource consumption optimisation – the managerial layer atop the technical base: Energy Management Systems (EnMS), KPIs of energy intensity per unit of output, dynamic shift and load planning, "energy budgeting" and savings verification. It is this layer that converts the technical potential of EE into sustained financial returns and TFP growth (Sitompul *et al.*, 2024). This means that EE variables (CapEx for modernisation, technology adoption, and managerial practices) should statistically correlate with indicators of profitability and productivity (margin, EBITDA, Return on Assets (ROA), energy intensity, TFP). At the same time, the strength of this relationship is mediated by access to finance and the level of digital maturity of the enterprise (Zhang *et al.*, 2025, Li *et al.*, 2025).

Renewables and energy-efficiency programmes are accompanied by a range of systemic barriers that determine the speed and scale of their deployment in global industry. The most significant of these is financial constraint: the high capital intensity of energy-efficiency projects and limited access to credit resources suppress firms' investment activity. Companies facing financial restrictions invest 30-40% less in energy-efficiency measures, whereas an easing of credit constraints can increase energy efficiency by an average of 7 percentage points (Zhang *et al.*, 2025). Another structural challenge is the high energy intensity of heavy industry, particularly the steel sector. Modernising production can reduce energy consumption by 108.6 kg of standard fuel per tonne of output, cut CO_2 emissions by 539 kg/t and generate an economic benefit of around 97.6 CNY/t (Na *et al.*, 2025). However, such results are achievable only with large-scale capital investment, which makes the decarbonisation process financially vulnerable in itself.

Equally critical is the technological gap and low level of digitalisation. The use of AI systems and digital energy management has proven capable of significantly reducing production energy intensity. At the same time, most companies in developing countries (Indonesia, Vietnam, Brazil) lack access to such technologies (Li *et al.*, 2025), creating a gap between potential and actual modernisation practices. An additional obstacle is institutional and regulatory instability. The absence of consistent, long-term energy-efficiency policy diminishes the effectiveness of implemented programmes. Improvements in energy productivity can stimulate TFP growth, but only under conditions of coherent state support and a stable institutional environment (Romero-Jordán *et al.*, 2025). Fragmented policies, on the other hand, undermine investor confidence and complicate the achievement of long-term outcomes (Amendola *et al.*, 2024). Profitability volatility is also observed due to political and market uncertainty. Even in developed markets, companies' financial results depend on macroeconomic conditions. Investment in renewables increases profitability indicators but does not reduce the Weighted Average Cost of Capital (WACC), indicating the persistence of financial risks (Dorigoni & Anzalone, 2024).

Another major challenge is investment risk under uncertainty. Even during energy crises, firms continue to invest in renewables and energy efficiency, but only on a limited scale and with elevated risk. This gives rise to the phenomenon of "risk-adjusted payback", in which a positive NPV does not guarantee the actual implementation of projects. The heterogeneity of results across sectors and countries forms a barrier to predictability: studies confirm the positive impact of renewables on company performance but highlight considerable variation depending on industry structure, institutional conditions and technological maturity (Sitompul *et al.*, 2024). Such variability underscores the need to adapt energy-efficiency strategies to national contexts, particularly in Ukraine, where the combination of wartime risks and limited financial resources shapes a unique configuration of barriers and opportunities for energy modernisation. Despite these systemic barriers, Ukraine shows gradual recovery of its energy sector and adaptation of industry to wartime conditions. The implementation of energy-efficiency programmes, the development of renewables and the modernisation of thermal generation remain priority areas for ensuring economic and energy resilience. Table 1 presents an analysis of indicator dynamics, enabling the tracing of trends in the transformation of the energy balance, investment structure and industrial sector profitability.

Table 1. Key energy indicators for Ukraine (2023-2024)

Indicator	2023	2024	Description
Installed RES capacity (GW, excluding HPP)	~7.0	~7.0	As of mid-2024: about 7 GW, including ~6 GW of solar generation. Losses in the southern regions (due to events in 2022) amount to 30-40% of capacity (~1.1-1.5 GW). Total losses from March-July 2024 = 9.2 GW. Approximately 3 GW of thermal generation has been restored thanks to repairs.

Table 1. Continued

Indicator	2023	2024	Description
Share of RES in electricity generation (%)	~10.0	8.7 (annual); 17-18 (summer)	In 2024, the share of RES decreased to 8.7% (compared with 9.4% in 2021). During summer, the share reaches 17-18%, while in winter RES covers only 4-7% of consumption. Nuclear power accounts for 55-60% (up to 7.5 GW of capacity in winter).
Volumes of "green" generation/purchases (thousand GWh)	7,936 (purchases by the SE "Guaranteed Buyer" from RES producers)	-	In 2023, the "Guaranteed Buyer" purchased 7,936 thousand MWh (+27% compared to 2022) totalling UAH 40.4 billion. Average tariff – UAH 5.13/kWh. No data available for 2024.
Investments in RES / DER (billion USD, cumulative / forecast)	~12+ (estimated)	15.5-23	Total RES investment at the beginning of 2022 was estimated at USD 12 billion. Forecast expenditure on DER development for 2023-2025 is USD 15.5-23 billion, which may ensure up to 5.6% system-wide cost savings.
Profit of enterprises (billion UAH, total)	776.4	947.3	In 2023, the total profit of large and medium-sized enterprises reached UAH 776.4 billion; in 2024 it increased to UAH 947.3 billion (+22%).

Source: compiled by the author based on BDO (2025), NERC (National Energy and Utilities Regulatory Commission of Ukraine) (2023), State Statistics Service of Ukraine (2025), International Energy Agency (2025a), DiXi Group (2025a,2025b), Energy Partnership Ukraine (2024), Ember (2024)

Table 1 provides important data on the energy situation in Ukraine, in particular on renewable energy sources, "green" generation volumes, investments in RES and DER, as well as financial indicators of enterprises. In 2023, the installed capacity of RES in Ukraine was approximately 7.0 GW, and this figure remained unchanged in 2024. The bulk of this capacity is solar generation, which accounts for about 6 GW. According to the table, attacks on energy infrastructure in the southern regions resulted in the loss of 30-40% of capacity, which is approximately equal to 1.1-1.5 GW. Total losses due to attacks between March and July 2024 amounted to 9.2 GW, but repairs restored about 3 GW of thermal generation. The share of RES in electricity production in 2023 was about 10%, and in 2024 this figure fell to 8.7% (for the year). However, in the summer, the share of RES can reach 17-18%, while in winter this figure drops to 4-7%. This highlights the seasonal dependence of electricity generation on RES, indicating the need to develop energy storage systems. In 2023, the State Enterprise "Guaranteed Buyer" purchased 7,936 thousand GWh of "green" electricity from RES producers, which is 27% more compared with 2022. This indicates a positive trend in supporting renewable energy sources in Ukraine. Data for 2024 are not available, which may point to difficulties with reporting or a reduction in purchase volumes due to national instability. At the beginning of 2022, cumulative investments in RES amounted to roughly USD 12 billion. The forecast for 2024 suggests an increase to USD 15.5-23 billion by 2030. This makes it possible to estimate potential cost savings of up to 5.6%, which is important for supporting the sustainable development of the renewable energy sector. In 2023, the profit of large and medium-sized enterprises in Ukraine totalled UAH 776.4 billion, and in 2024 this figure rose to UAH 947.3 billion, which represents an improvement of 22%. However, despite overall profit growth, around 22.1% of enterprises remained unprofitable, indicating an uneven impact of energy efficiency programmes at the level of individual companies.

Overall, the data in Table 1 indicate a certain stability in Ukraine's energy sector for 2023-2024, although there are several challenges: capacity losses due to military actions and seasonal fluctuations in the share of RES indicate the need to improve infrastructure for a stable energy supply. The growth in "green" generation and investment in RES and DER is a positive sign for the development of the renewable energy sector, but this process requires further investment and political stability to ensure long-term energy independence. The growth in corporate profits indicates an improvement in the financial situation in Ukraine, but to ensure business stability, it is important to reduce the share of loss-making enterprises and increase the efficiency of energy programmes. For a more detailed comparison of the impact of energy efficiency and RES development programmes on key energy and financial indicators, a comparative analysis of three leading industrial companies in Ukraine – Metinvest, Interpipe and ArcelorMittal – was conducted. Table 2 provides data on energy consumption, energy costs, investments and profitability of these companies in 2023-2024.

Table 2. Comparative energy and financial indicators of industrial companies in Ukraine (2023-2024)

Indicator	Metinvest Holding	Interpipe	ArcelorMittal	Comment/trend
Total energy consumption	≈ 8,200 million kWh	ND (not disclosed in open sources)	≈ 4,800 million kWh (estimate based on average consumption in 2021-2022, adjusted for reduced production due to martial law)	In 2024, Metinvest reduced energy consumption through modernisation and energy audits; ArcelorMittal demonstrates stable consumption despite production restrictions
Share of renewables in energy consumption	12% (own solar PV plants, biogas projects, external green-energy suppliers)	ND (not disclosed; partial use of own solar PV plants at industrial sites)	≈ 10% (purchase of "green" electricity from ArcelorMittal Energy suppliers)	Metinvest has the highest level of RES integration, while ArcelorMittal is gradually increasing the "green" share in its consumption structure

Table 2. Continued

Indicator	Metinvest Holding	Interpipe	ArcelorMittal	Comment/trend
Energy carrier expenditures, million USD	USD 1,080 million	ND (integrated into production cost)	≈ USD 290 million (a 12% y/y increase due to rising electricity and natural gas tariffs)	Metinvest sees a decrease in energy costs thanks to production optimisation, while ArcelorMittal sees an increase due to price pressure
CAPEX for energy efficiency	USD 145 million (investments in decarbonisation, equipment modernisation, and energy audits)	USD 31 million (not itemised separately, included in total CAPEX)	≈ USD 110 million (investments in decarbonisation programmes, blast furnace modernisation, and energy audits)	Largest investments in ArcelorMittal as part of the decarbonisation programme
EBITDA	USD 2,519 million	USD 337 million	≈ USD 420 million (estimate for the local division based on its share of ArcelorMittal's global EBITDA for 2024 = USD 7.1 billion)	Increased profitability across all companies due to improved operational efficiency and energy management
EBITDA margin	18%	34%	≈ 15%	Reflects Interpipe's higher operational efficiency and ArcelorMittal's gradual recovery
Net profit	USD 850 million	USD 280.48 million (2024), USD 252.89 million (2023)	≈ USD 120 million (a slight increase following a loss-making 2022)	General trend towards a revival in profitability after the 2022 crisis
Core strategy	Modernisation, digitalisation	Digital energy management	Decarbonisation, renewables (RES)	Companies' approaches are aimed at increasing efficiency and reducing their carbon footprint
Identified effects	Reduction of OPEX, ↑ TFP	Reduction of energy intensity	Reduction of CO_2 emissions	Confirms the economic and environmental feasibility of energy-efficient investments

Note: Interpipe's energy KPIs (total energy consumption, share of RES, individual energy costs, CAPEX for energy efficiency) are not disclosed in public reports for 2023-2024. The company publishes financial indicators in IFRS format (International Financial Reporting Standards – reflecting only the company's financial indicators, therefore energy data (kWh, RES, energy costs) are not included), non-financial (ESG) data on energy are not publicly available or are not detailed. The indicators for ArcelorMittal are marked as estimated (≈) due to the absence of official energy KPIs in the public reports of the Ukrainian division, calculated based on the aggregated data of the ArcelorMittal group (2023-2024)
Source: compiled by the author based on Metinvest Holding (2023), Interpipe (2023; 2024), ArcelorMittal (2024)

Ukrainian industrial companies are gradually integrating energy-efficient and environmentally friendly approaches into their production activities. Metinvest Holding has made the most systematic transition to renewable energy sources and has invested heavily in modernisation. Interpipe maintains the highest operational efficiency, reflected in an EBITDA margin of 34%, although the company does not disclose detailed energy performance indicators. ArcelorMittal is focusing its investments on decarbonisation projects and the restoration of production capacity after the crisis of 2022. In 2023-2024, Ukrainian industrial producers are gradually moving from energy consumption based on an inertial model to sustainable development strategies focused on energy efficiency, digitalisation and carbon emission reduction. This indicates the convergence of corporate policies with European requirements and the formation of the foundations for a decarbonised industry.

The Ukrainian energy sector has remained relatively stable despite significant losses in generating capacity and high risks to infrastructure. Although the share of renewable energy sources remains limited, the recovery of investment activity and the growth in industrial profitability indicate the gradual adaptation of the economy to new energy and financial realities. The results of the study revealed that energy efficiency is one of the key factors in increasing the TFP of industrial enterprises on a global scale. This is consistent with P. Montalbano *et al.* (2022), which showed that investments in EE not only contribute to reducing operating costs but also create long-term competitive advantages through increased technological and production efficiency. The authors proved that energy-efficient enterprises have higher financial stability, especially in periods of market volatility. Similar conclusions were obtained in this study: the implementation of sustainable energy consumption programmes has a positive impact on profitability, margins and cash flow stability. Both approaches emphasise the multiplier effect of EE, which manifests itself in increased TFP, EBITDA and reduced risks. Improving energy efficiency is a systemic driver of economic productivity and competitiveness of enterprises, even with limited investment opportunities.

A study by A. Ketenci & M. Wolf (2024) shows that even small manufacturing enterprises not associated with energy-intensive industries can achieve significant energy savings through the implementation of structured energy management. The authors proved that internal energy audits, equipment modernisation and process optimisation reduce energy consumption by 20-30%, increasing production efficiency without significant capital investment. They emphasised that the effectiveness of EE programmes depends primarily on management consistency, cost control and the integration of digital monitoring tools. These results are consistent with the findings of the current study, which also confirms that the phased implementation of energy modernisation programmes at Ukrainian enterprises (in particular Interpipe and Metinvest) provides financial returns through reduced OPEX and increased operational stability. Systematic energy management is a determining factor in the effectiveness of modernisation processes and business sustainability. The work of N. Taghavi (2022) demonstrated that improving energy efficiency in manufacturing operations is achieved through the practical integration of EE principles into daily production management processes, in particular through improved operational discipline, energy consumption control and the implementation of management optimisation mechanisms. The author emphasised that systematic operational control ensures sustainable energy modernisation results even without large-scale investments. The current study confirmed similar patterns: the implementation of EnMS systems, energy intensity KPIs and energy budgeting allows energy savings to be reflected in the financial results of enterprises. Systematic process optimisation, from reducing downtime to load planning, is the main mechanism for improving operational efficiency. Both studies show that it is managerial consistency, and not just technical modernisation, that ensures a stable economic return from EE programmes, indicating the practical significance of energy management methods in improving the financial performance of industrial enterprises.

The results of the study confirmed that staff training and organisational knowledge accumulation have a significant impact on the energy efficiency of industrial enterprises. This correlates with the findings of J.Jr. Aduba *et al.* (2025), which found that continuous employee training systems can reduce energy consumption by 10-15% and increase overall productivity. The authors emphasised that the effectiveness of EE programmes depends not only on technical investments, but also on the managerial capacity of staff to use innovative practices. This approach confirmed the importance of human capital as a mediator between energy modernisation and financial results. The formation of competencies and the development of an energy efficiency culture are necessary prerequisites for sustainable economic growth in industry. Y. Zhang *et al*. (2024) proved that digitalisation is one of the key factors in improving the energy efficiency of industrial enterprises. The authors found that the introduction of Internet of Things (IoT) technologies, AI and automated monitoring systems can reduce energy consumption by 10-12% and increase energy productivity by 8-10%. It was shown that the digital maturity of an enterprise acts as an intermediary between technological innovations and economic results, ensuring a stable return on investment in modernisation. The researchers also emphasised that the integration of intelligent energy management systems contributes to reducing risks and increasing the financial stability of the business. The findings were consistent with the results of the current study on the implementation of ACES, EnMS and predictive maintenance technologies at Interpipe and Metinvest, which delivered significant energy savings. Digital transformation in Ukrainian industrial companies has shown a similar trend – a reduction in OPEX, an increase in TFP and an increase in profit margins. Digitalisation acts as a catalyst for the economic effect of energy modernisation and a critical factor in increasing the competitiveness of enterprises. Thus, energy efficiency is a systemic factor in the growth of productivity, profitability and sustainability of industrial enterprises, ensuring a reduction in operating costs, an increase in technological efficiency and the formation of long-term competitive advantages.

The results of the study showed that during times of military risk, the energy resilience of industrial enterprises is formed through a combination of energy efficiency, diversification of energy sources, and digital monitoring. Comprehensive energy modernisation reduces dependence on external suppliers and maintains production stability even in crisis conditions. Similar patterns were identified in a study by P. Lebepe & T.N.D. Mathaba (2025), which systematised the key challenges and strategies for strengthening the energy resilience of enterprises, in particular through the development of energy management systems and the decentralisation of energy supply. The authors concluded that companies with a high level of energy control recover their operational efficiency more quickly after disruptions. The results of both studies confirmed that energy sustainability management is a fundamental factor in the financial stability of industrial companies. The results of the study confirmed that the implementation of energy monitoring systems and regular assessment of energy consumption efficiency (in particular through ACES and EnMS systems) provide a significant reduction in energy costs and production costs without the need for large-scale investments. Structured energy management and technological modernisation enable stable energy savings and increased profitability even in conditions of military instability. Similar results were reported in a study by D. Al Momani *et al.* (2023), where an energy audit at a food industry enterprise reduced energy consumption by 18% without significant capital investment. The authors demonstrated that systematic maintenance, process optimisation and continuous monitoring are effective sources of sustainable savings. The conclusions of both studies indicate that energy audits are a basic tool for energy modernisation, transforming operational savings into sustainable growth in companies' financial results.

A. Berner *et al*. (2022) investigated the effects of the rebound effect in German industry, showing that 15-25% of the savings achieved by EE complexes are offset by an increase in production activity. The authors concluded that in order to maintain financial efficiency, it is necessary to integrate management mechanisms for consumption control and energy intensity KPIs. This was consistent with the results of the current study, which noted the usefulness of EnMS, energy budgeting and KPIs in capturing savings. The EE effect must be supported by systematic management to avoid losing the results of modernisation. Digitalisation is not only a technical but also a strategic factor in the financial stability of enterprises. Digital technologies are shaping a new level of energy consumption management, turning EE into a competitive advantage. The results of the study showed that, despite the risks of war and loss of capacity, the Ukrainian industrial sector is demonstrating a gradual recovery in investment activity and improved financial results. This is consistent with the findings of C.-C. Lee & H. Wen (2025), who demonstrated that the participation of enterprises in global value chains (GVCs) is a key catalyst for improving energy efficiency. The inclusion of companies in international production and distribution networks leads to stricter requirements for energy management, environmental reporting and process standardisation, as transnational partners increasingly demand compliance with ESG (Environmental, Social, Governance) principles. Such conditions encourage industrial enterprises to implement energy-saving technologies, energy consumption monitoring systems, digital energy flow management solutions (AI-based energy management) and to develop internal decarbonisation policies. Global interaction is not only an external stimulus for energy efficiency, but also a mechanism for long-term consolidation of the effects of modernisation, integrating Ukrainian enterprises into the system of sustainable industrial development. Thus, energy efficiency is not only a technical or environmental priority, but also a strategic factor in macroeconomic and corporate sustainability. Its strengthening through digital solutions, human capital and international integration creates the basis for the formation of a competitive, low-carbon and innovative model of industrial development, particularly in Ukraine in the post-war period.

Conclusions

The study results showed that effective energy modernisation increases EBITDA, profit margins and energy productivity, while reducing financial and operational risks. In industry, the effect of energy efficiency is manifested through a reduction in specific energy costs and OPEX volatility, an increase in TFP and a reduction in downtime and losses. The easing of credit restrictions increases the energy efficiency of enterprises by an average of 7 percentage points, while the lack of financing reduces EE investments by 30-40%, which directly affects margins and EBITDA.

Digitalisation is a strategic driver of energy modernisation: the use of AI-based energy management and predictive maintenance systems provides additional resource savings, increases the flexibility of production processes and reduces the payback period for modernisation projects. This demonstrates the close link between a company's level of digital maturity and its financial stability. In 2023-2024, leading Ukrainian manufacturers are showing steady progress: Metinvest Holding and ArcelorMittal are reducing their energy consumption (4.8-8.2 billion kWh), the share of RES is growing to 10-12%, and the combined CAPEX for energy efficiency of the three companies (Metinvest, Interpipe and ArcelorMittal) exceeds USD 250 million, accompanied by growth in EBITDA and net profit. At the same time, the implementation of RES and energy efficiency programmes is accompanied by a number of systemic barriers. Key challenges include financial constraints and the high capital intensity of projects, which hinders investment activity. Strengthening the credit infrastructure can significantly increase the effectiveness of energy modernisation. Equally significant are technological gaps and low levels of digitalisation in energy-intensive sectors, as well as institutional instability, which reduces investor confidence and slows down the implementation of long-term programmes. Only a comprehensive state policy and access to modern technologies can ensure the transition from situational to structural energy efficiency effects. Despite the difficult conditions, Ukraine is showing a gradual recovery in the energy sector – in 2024, approximately 7 GW of renewable energy capacity will be preserved, and the profits of industrial enterprises will increase by 22% compared to the previous year. It is projected that the development of DER in Ukraine will require USD 15.5-23 billion in investments by 2030, providing up to 5.6% in systemic energy cost savings. This creates the potential to strengthen the competitiveness of national industry after the war. Further research should focus on econometric analysis of the relationship between investment, digitalisation and the efficiency of Ukrainian enterprises, and the development of national energy efficiency indicators in line with international standards.

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Conflict of Interest

None.

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Економічні наслідки впровадження програм сталого енергоспоживання у промислових компаніях

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Анотація. Метою дослідження було визначення впливу управлінських та технологічних змін у сфері енерговикористання на результати діяльності промислових підприємств. Методологія базувалась на теоретичних, емпіричних і порівняльних методах для аналізу ефектів енергоефективності та сталого споживання енергії. Визначено економічні механізми впливу інвестицій у energy efficiency – зниження питомих енергетичних витрат і волатильності Operating Expenditure, підвищення Total Factor Productivity та хеджування регуляторних і цінових ризиків. Підкреслено, що ефект значно посилюється за наявності цифрових технологій (Artificial Intelligence-based energy management, predictive maintenance) і доступу до фінансування, тоді як жорсткі кредитні умови залишаються ключовим бар'єром для реалізації energy efficiency проєктів. Встановлено, що інвестиції в енергоефективність знижують енерговитрати й ризики, підвищують операційну ефективність і конкурентоспроможність завдяки модернізації та цифровізації, тоді як головними перешкодами залишаються обмежене фінансування й низька цифрова зрілість підприємств. Metinvest Holding у 2024 скоротив енергоспоживання до ≈ 8,2 млрд кВт·год і спрямував 145 млн дол. на енергоефективність, Interpipe зберіг найвищу маржу Earnings Before Interest, Taxes, Depreciation, and Amortisation – 34 %, тоді як ArcelorMittal інвестував ≈ 110 млн дол. у декарбонізаційні програми. Виявлено, що в Україні частка відновлювальних джерел енергії у виробництві 2024 складає 8,7 %, 17-18 % влітку, 4-7 % взимку, прибуток великих/середніх підприємств: 776,4 → 947,3 млрд грн (+22 %), збиткові компанії ~22,1 %. Українська промисловість довела, що навіть у кризових умовах енергоефективні програми забезпечують зниження витрат, зростання прибутку та підвищення стійкості підприємств. Доцільно впроваджувати комплексні програми енергоефективності – поєднання технічних рішень, цифрових систем управління та фінансового моніторингу економії. Результати можуть бути використані підприємствами та урядовими структурами для підвищення енергоефективності й розробки стратегій сталого енергоспоживання, зокрема в Україні

Ключові слова: рентабельність; оптимізація; прогнозування; ресурсоефективність; енергопродуктивність; хеджування