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Eco-Friendly Entrepreneurship and Innovations: The Impact of Energy-Efficient Technologies on Business Practices

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Abstract

This article aims to study the impact of energy-saving technologies on business processes in the context of green entrepreneurship and innovation, analysing their implementation and interconnection with efficiency, sustainability, and competitiveness. During the article's writing, general scientific methods of cognition were applied, namely the analysis of literary sources, statistical data, methods of systematisation and generalisation, and comparative analysis. For the research, a survey of 24 experts in ecology and energy, including professors and associate professors from NTU "Dnipro Polytechnic" and the Ukrainian State University of Chemical Technology, was conducted. The evaluations were processed by calculating average values using Excel's "AVERAGE" function and correlation analysis using "Pearson's Correlation" in the JASP program. The study showed that implementing energy consumption optimisation (75.25), combined heat and power production (76.67), and energy-efficient materials (78.3) significantly reduces energy costs and enhances the sustainability of production processes. Moreover, the correlation analysis confirms the impact of power generation ($r = -0.38$; $p = 0.067$) and replacement of energy equipment ($r = -0.3$; $p = 0.15$) on auxiliary business processes, highlighting the importance of these technologies for improving business efficiency. Thus, green entrepreneurship and energy-saving innovations contribute to environmentally friendly production and ensuring long-term competitiveness.

Keywords: *Green entrepreneurship; energy-saving technologies; digital technologies; business value; business process transformations.*

Introduction

In today's world, countries increasingly focus on transitioning to a green and circular economy, recognising that sustainable development is crucial for future growth. Currently, a large number of countries have high potential and opportunities for the implementation of green technologies and the promotion of environmental entrepreneurship. According to the Green Transition Navigator, Canada has a high Green Complexity Potential (0.99) due to its effective wastewater management, developments in drinking water purification, and renewable energy sources. The United States, with one of the highest Green Complexity Indexes (2.9), takes necessary measures annually to ensure efficient energy consumption and carbon storage technologies (Green Transition Navigator, 2022). Conversely, developing countries and those experiencing economic or environmental crises have significantly lower indicators. For example, Ukraine, which is currently at war, has a Green Complexity Potential of 0.53; and Somalia, which is currently struggling with severe droughts, food insecurity, natural disasters, and water shortages, has a low Green Complexity Index (-0.72) and Green Complexity Potential (-0.83) indicators. In this context, Andres and Mealy highlight the need to use these indicators to achieve maximum efficiency for countries without harming the planet, creating unprecedented opportunities for the growth of a wide range of environmentally friendly products, from water conservation to waste recycling and air pollution monitoring (Andres & Mealy, 2021). Conti et al. (2018) studied the features of the transition to a green economy in the significant innovative countries of the world (USA, Japan, and the EU). The authors concluded that in recent years, the EU has reduced the fragmentation of the innovation system in renewable energy sources, mitigating the effects of climate change and developing renewable energy technologies, compared to the lesser efforts of the USA and Japan

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in this context. However, the study by Arora et al. (2023) notes the high productivity of green entrepreneurship institutions in the USA and the UK. Different approaches and conclusions of scientists necessitate comprehensive research that considers not only quantitative indicators but also current cases, thus providing a comprehensive analysis of the impact of green technologies on the business processes of modern enterprises and the economy.

This work aims to study the impact of energy-saving technologies on transforming business processes in the context of green entrepreneurship and innovation. The article seeks to analyse the state of implementation of advanced energy-saving technologies and their interrelation with modern enterprises' efficiency, sustainability, and competitiveness.

Literature Review

Today, the rapid development of the global business environment and the intensification of environmental problems require implementing new forms and types of entrepreneurial activities. Modern business conditions necessitate adherence to the principles of sustainable development, which include reducing emissions, decreasing resource use, attracting additional funding, and implementing energy-efficient technologies (Chygryn et al., 2019; Desyatnyuk et al., 2024; Shevchenko et al., 2023). According to the study by Kumar and Kiran (2017), these measures are necessary to minimise adverse environmental impacts while maintaining high rates of entrepreneurial development.

According to Sheldon's research (2016), the green economy focuses on reducing environmental impact through the efficient use of resources. Meanwhile, its combination with the circular economy, according to Morseletto (2020), creates a foundation for maximum recycling and reuse of materials, thus reducing waste. In this context, green entrepreneurship and innovation play a crucial role, capable of shifting business processes towards the development of more environmentally friendly and energy-efficient technologies (Duran, 2024; Modi, 2023; Odeyemi et al., 2024; Krysovatyy & Ptashchenko, 2023).

Green entrepreneurship combines social responsibility and economic benefits, encouraging businesses to implement innovative solutions (Cader et al., 2022; Lotfi et al., 2018; Khaminich et al., 2020). Bobkova et al. (2020) says it includes using renewable energy sources, developing environmentally friendly products, and implementing processes that reduce greenhouse gas emissions. Innovations in this field are often associated with high-tech solutions that allow for more efficient use of resources (Sun et al., 2023) and optimisation of production processes (Feng et al., 2022). Moreover, Liu and De Giovanni (2019) note that environmental performance positively affects demand, leading to increased production volumes and, in turn, harming environmental performance due to negative externalities.

Changes in business processes, such as improving recycling processes, reducing emissions and waste, optimising logistics, and more, driven by green innovations, contribute to enhancing the efficiency and competitiveness of modern companies (Naumenko et al., 2020; Reznikova et al., 2024; Tjahjadi et al., 2020). Enterprises that integrate energy-saving technologies gain competitive advantages by reducing operational costs and enhancing their reputation among consumers and investors who increasingly value environmental responsibility (Cader et al., 2022). For example, Ochieng et al. (2014) note that the integration of energy-efficient technologies in the activities of UK supermarkets affects consumer behaviour and provides a competitive edge through ecological elements of corporate social responsibility. Meanwhile, Esty and Winston (2009), using the "Green to Gold" approach, explored examples of Toyota, IKEA, GE, and Nike in the context of creating long-term value, reducing costs, mitigating risks, increasing revenues, and building strong brands by embedding environmental thinking into business. Thus, green entrepreneurship and innovations are vital components of modern business strategies, enabling the reduction of the environmental footprint and achieving sustainable development and prosperity in the face of global challenges.

According to Kharchenko's research, the main factors that enhance the practical application of environmental innovations are the limitation of financial resources, necessitating the search for new, less expensive technologies, the inadmissibility of government incentives for innovative greening of production,

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the lack of effective mechanisms for interaction between the state and entrepreneurial structures, the incredible complexity of technological processes, the increase in waste, and the imperfection of environmental legislation. To improve environmental inventions and innovations, it is necessary to develop government co-financing programs, improve connections between market actors, and refine institutional elements, such as developing ecological technoparks, business incubators, and technology transfer centres (Kharchenko, 2021).

Applied Methods

In the course of the study, the following methods were used: comparative analysis was employed to compare the indicators of ecological complexity and competitiveness of countries in the field of green technologies and sustainable development; statistical data analysis was used to examine the advantages and challenges in the field of environmental innovations; case analysis was used to study the current state and development prospects of the countries under investigation; the systematisation method was applied to identify and characterise modern energy-saving technologies; literature source analysis was used to develop a classification of key business processes of enterprises; the generalisation method was used to formulate conclusions regarding the impact of energy-saving technologies on the business processes of enterprises.

To assess the impact of energy-saving technologies on the business processes of enterprises, a survey was conducted with 24 leading figures in the field of ecology and energy, including seven professors and nine associate professors from the Department of Ecology at NTU "Dnipro Polytechnic" and five professors and three associate professors from the Department of Energy at the Ukrainian State University of Chemical Technology. Based on the obtained evaluations, weighted average scores for each indicator were calculated using the "AVERAGE" function in Excel. To analyse the degree of impact and the stability of the relationship between the implementation of energy-saving technologies and the efficiency of enterprises' business processes, the "Pearson's Correlation" tool in the JASP program was used.

Research Results

The issue of limited energy resources and their inefficient use is becoming global in scale and is the subject of active discussion among both state leaders and the scientific community (Chygryn et al., 2019; Duran, 2024; Kumar & Kiran, 2017; Modi, 2023; Odeyemi et al., 2024). Developed countries worldwide try to address current environmental problems by continuously searching for new, more efficient energy sources. In this context, green entrepreneurship and innovative solutions are essential, as environmental technologies help reduce resource consumption and transform business processes, stimulating economic development and ensuring economic sustainability.

The Green Transition Navigator (2022) data were analysed to assess countries' ecological complexity and competitiveness in green technologies and sustainable development. Using the random sampling method, countries with different Green Complexity Index (GCI) rankings were selected to analyse their level of ecological competitiveness, as presented in Figure 1.

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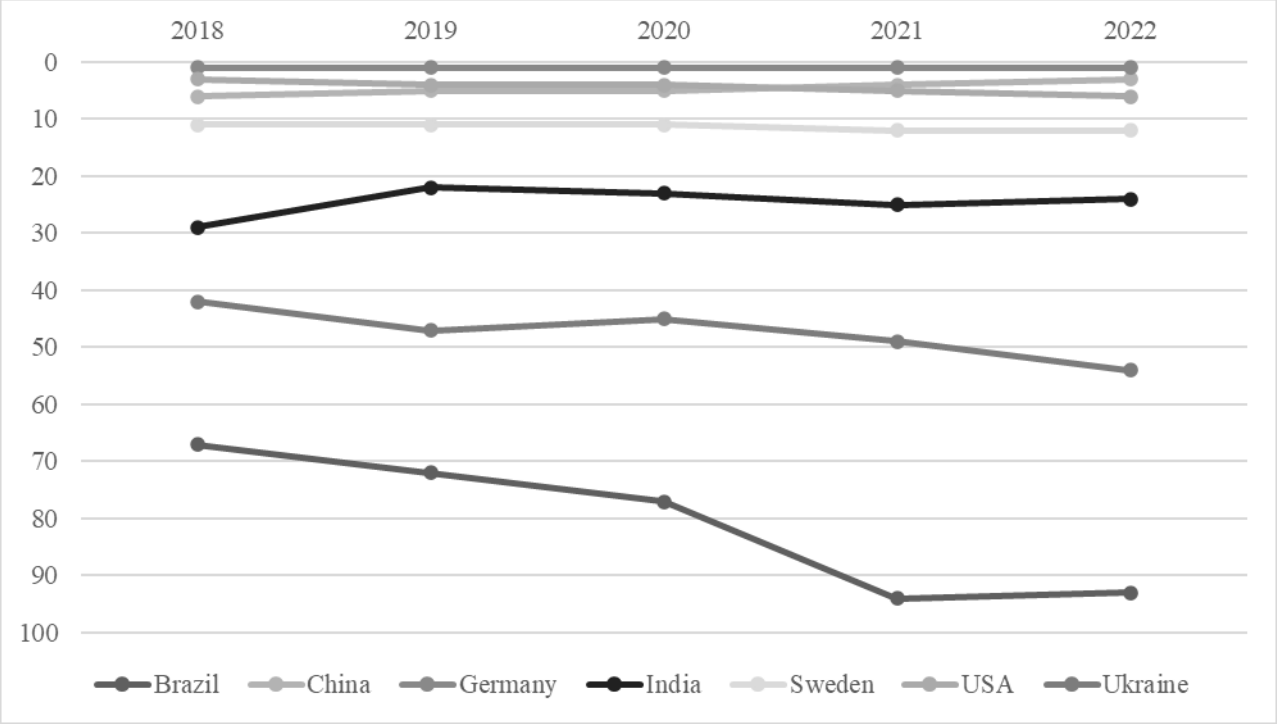

Figure 1. Green Complexity Index Rating for 2018–2022

Source: compiled by the author based on (Green Transition Navigator, 2022)

During the period from 2018 to 2022, Brazil faced difficulties in adapting to new environmental requirements and standards, resulting in a decrease in its ranking to 94. In first place, with a share of green exports at 16.93%, is Germany, which is currently one of the world's leading exporters of air pollution control technologies. Meanwhile, green technology imports, which account for 12.07%, are aimed at wastewater management and drinking water purification, confirming the country's comprehensive approach to environmental challenges. India (24) shows gradual improvement in its environmental performance due to increased energy consumption technologies and carbon storage efficiency.

In turn, China has shown significant improvement in environmental performance, with the best green export (13.36%) and import (8.75%) categories being efficient energy consumption technologies and carbon capture and storage, highlighting the country's focus on implementing innovative environmental technologies. The stability of Sweden's ranking (12) is primarily due to its innovative policy in renewable energy, effective air pollution control, the integration of environmental standards into industry, support for scientific research, and a high level of environmental awareness among the population. The main direction of the USA's development in ecology remains renewable energy, driven by high export (11.18%) and import (10.68%) figures of energy technologies.

It is also worth noting Ukraine's relatively high ranking (54), especially considering the active hostilities in the east of the country and the environmental disasters caused by terrorist acts of the Russian army. The share of green exports (3.74%) and imports (9.52%) mainly comprise energy technologies, wastewater management and drinking water purification technologies, respectively. Additionally, it is essential to assess the identified countries in terms of their achievements and challenges in environmental innovations. A comparative analysis was carried out using current Environmental Performance Index indicators presented in Figure 2.

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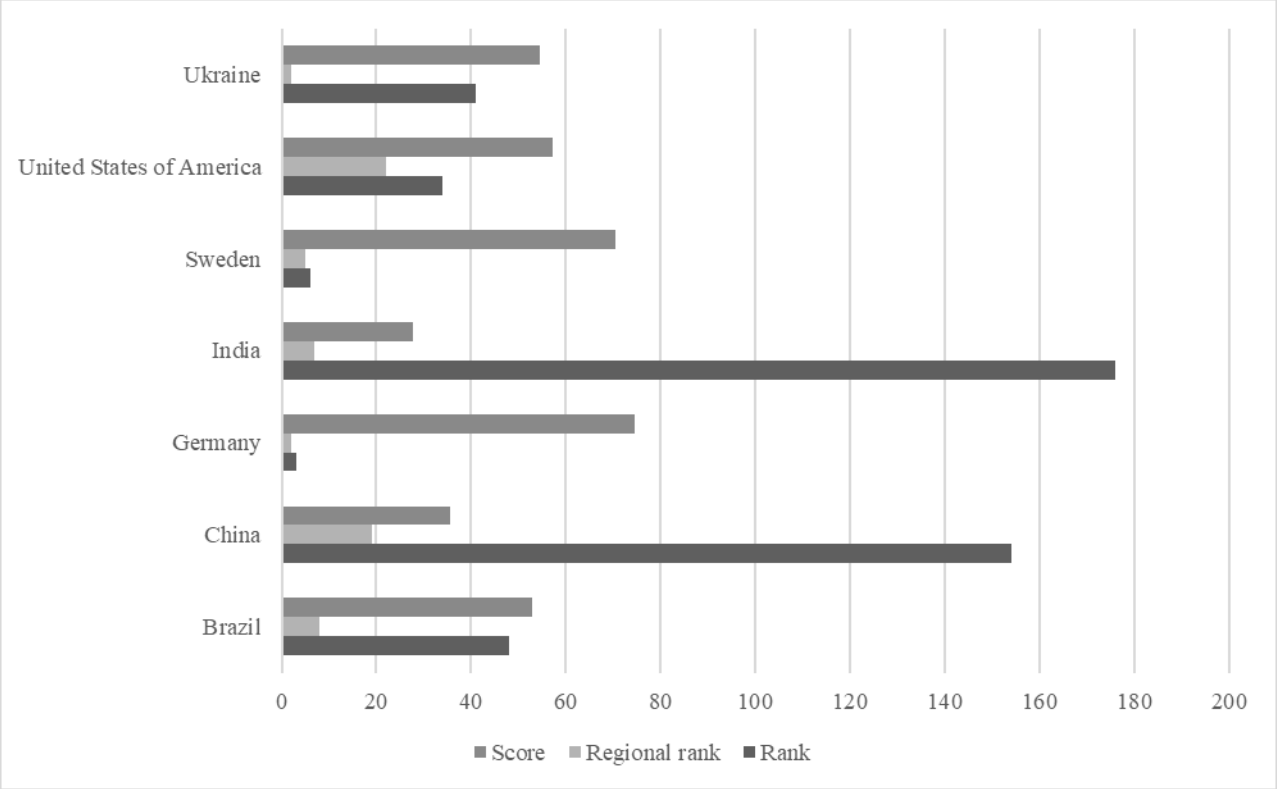

Figure 2. Current Environmental Performance Index of Countries in 2024

Source: compiled by the author based on (EPI, 2024)

According to the Environmental Performance Index, countries such as the USA (34), Brazil (48), China (154), and India (176) have relatively low rankings despite high environmental competitiveness based on the previous analysis. In contrast, Germany (3) and Sweden (6) consistently show high rankings among the analysed countries, justified by their significant achievements in environmental innovations. Meanwhile, Ukraine (41) demonstrated a significantly higher EPI ranking than its GCI, as it has implemented waste management improvements and reduced industrial environmental impact amid the war. Thus, the quantitative indicators of countries' environmental competitiveness differ from the current state of implementation of environmental technologies, indicating the need for further development and implementation of innovative measures in environmental protection and strengthening resource management strategies to achieve more sustainable development in the analysed countries.

The significant disparity in China's indicators is due to its energy reform, primarily focused on preventing increases in overall energy consumption and boosting investments in energy-saving and innovative technologies such as renewable energy technologies and energy-efficient materials. This policy leads to a growing trend in renewable energy investments; for instance, in 2019, China invested USD 83.4 billion in the development of renewable capacities, and by 2021, the country accounted for 33% of the global renewable electricity capacity (Dogah et al., 2024).

Discussion

In the context of developing energy-saving technologies by 2030 to fulfil the objectives of the Global Development Agenda adopted at the UN Summit, humanity must make significant shifts towards promoting the ideas of reducing natural resource consumption, minimising waste and pollution, and implementing environmentally safe technologies and innovations. This will ensure broad access for the world's population to the results of social development (Musina & Kvasha, 2017). According to the research of these authors, the entire value of natural resources should be considered a capital factor in the strategy of green production. To develop the latter, state pricing and taxation mechanisms that stimulate resource

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conservation should be applied, and environmental standards, subsidies, grants, and green business development programs should be introduced.

Currently, the most exciting and relevant case in the global context is the development of entrepreneurial activities of Ukrainian businesses, given the massive attacks by Russia on Ukraine's energy system, resulting in an electricity generation deficit of over 3500 MW (Apostolaka, 2024). Thus, in a complex economic and political situation, Ukraine faces the urgent issue of ensuring economic security, with the problem of high energy consumption, improving energy efficiency, and developing renewable energy becoming more acute (Alekseieva et al., 2023). At the same time, besides systematic outages and the threat of intensified attacks, a significant problem remains the reluctance of citizens and business representatives to reduce electricity consumption (Sotnyk et al., 2023).

Implementing innovative energy-saving technologies (see Table 1) is a critical factor in forming new approaches to resource management, particularly energy resources. This opens new prospects for entrepreneurship and promotes the development of an environmentally oriented business environment.

Table 1. Features of Modern Energy-Saving Technologies

Energy-saving technologies	Features
Technologies for optimising energy consumption	Energy optimisation technologies include heat exchangers, variable-speed electric motors, atmospheric air, and steam to reduce energy consumption in industrial processes and use heat efficiently.
Energy-efficient materials and systems	The use of high thermal conductivity insulation, energy-efficient windows and doors, energy management technologies, and the introduction of new energy-saving systems.
Combined heat and power generation	A technology that simultaneously generates heat and electricity from a single source saves fuel resources and reduces CO^2 emissions, which is especially important in times of increased energy demand.
Cogeneration of electricity, heat and cold	Cogeneration allows efficient use of the heat generated by electricity production for heating in winter and cooling in summer, which reduces energy consumption for air conditioning systems and technological processes.
Replacement of energy-intensive outdated equipment with modern ones	It includes replacing outdated, energy-intensive equipment with modern, efficient means, which can significantly reduce energy costs and improve the overall energy efficiency of the enterprise.
Installation of industrial voltage regulators	A technology that solves the problem of unstable power supply by replacing demolished power grids and outdated transformer substations with modern devices that contribute to more efficient electricity use and cost reduction.

Source: compiled by the author based on (Wiedermann et al., 2022)

Moreover, the integration of digital technologies reduces costs, enhances resource management efficiency, and optimises production processes (see Table 2), which, in turn, positively impacts business value. Innovative approaches to energy saving and resource management contribute to lowering operational costs and increasing companies' competitiveness.

Table 2. Classification of Business Processes Based on Basic Categories

Category	Description
Key business processes	They cover the processes directly used to create the main products or services that are the organisation's primary source of revenue. They aim to

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		create customer value and add value through service outcomes relevant to external customers.
Ancillary business processes	Servicing business processes	These processes provide the structural support and infrastructure conditions for the effective functioning of core business processes. They organise the resources required to run and support operational functions, including the management of information, finance, human resources, and other aspects that affect the efficiency and effectiveness of the core processes.
	Management business processes	These processes cover management activities at all levels of the organisation, including managing individual business processes and the system as a whole. They aim to improve the efficiency and effectiveness of auxiliary business processes by implementing strategic and tactical decisions, management practices and tools to achieve the enterprise's strategic goals.
	Business development processes	These processes are aimed at creating new or improving existing products, services, or processes that lead to the creation of additional value for the organisation in the long term. They include innovation strategies, research and development of new technologies, and processes contributing to the organisation's competitiveness and sustainable development.

Source: compiled by the author based on (Chernobai & Duma, 2015; Mironova et al., 2022; Taymouri et al., 2021)

Implementing innovative technologies and ecological principles in entrepreneurial activities is essential for sustainable development and economic stability. This allows for forming a new paradigm of economic growth based on the principles of sustainable development and the rational use of resources. Therefore, an expert survey was conducted among 24 researchers who studied current issues in ecology and energy to determine the impact of the previously identified energy-saving technologies on business processes. The results of the expert evaluation are presented in Figure 3.

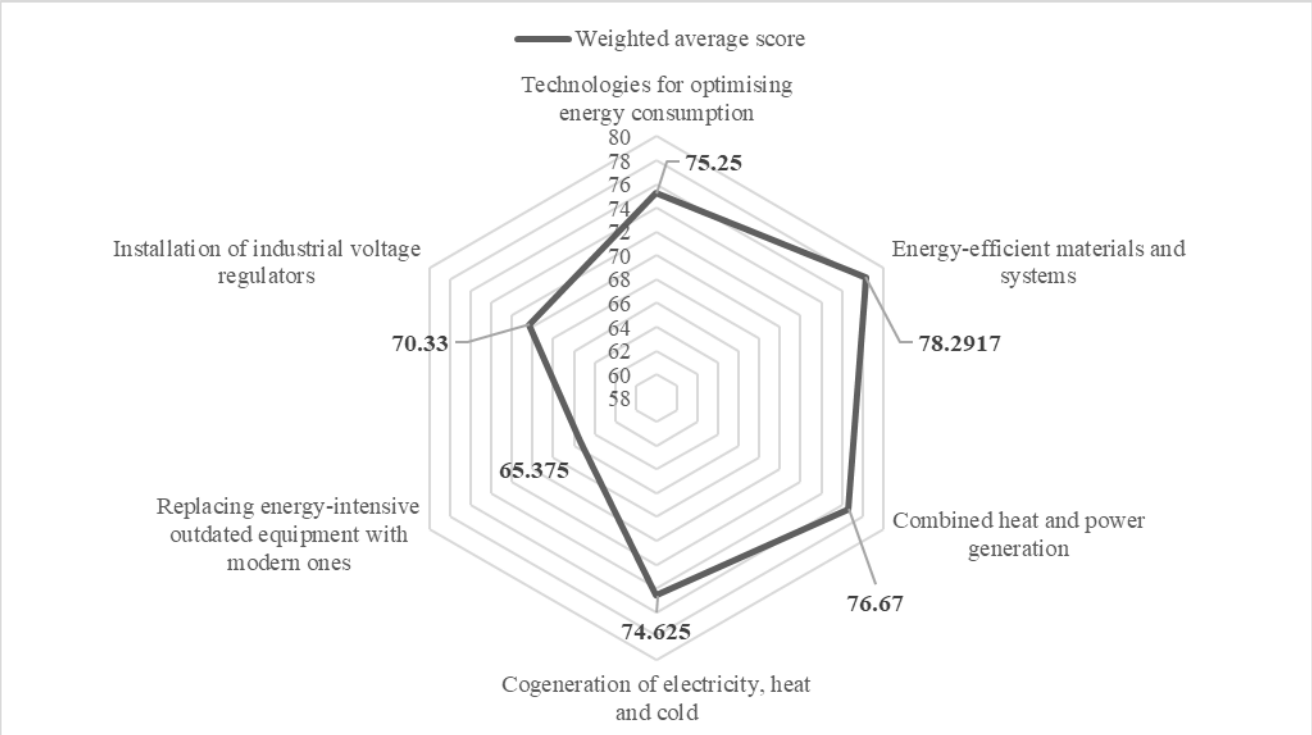

Figure 3. Weighted Average Score of the Impact of Energy Saving Technologies on Enterprise Business Processes

Source: compiled by the author based on the questionnaire

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Based on the calculation of weighted average scores obtained from the expert survey, it was determined that energy-saving technologies have significant potential to improve the efficiency of business processes in enterprises. Specifically, applying energy consumption optimisation technologies (75.3) allows enterprises to use energy resources more efficiently, thereby reducing costs and environmental impact. Combining heat and power production (76.7) enables enterprises to utilise thermal and electrical flows effectively to optimise energy costs and increase process productivity. Additionally, using energy-efficient materials (78.3) reduces energy costs and enhances the long-term sustainability of production processes. However, we conducted a correlation analysis based on previously obtained data to analyse the degrees of impact and the stability of the relationship between the implementation of energy-saving technologies and the efficiency of business processes in enterprises. The results of the correlation analysis were obtained using the JSAP program (Pearson's Correlation tool) and are presented in Table 3.

Table 3. Correlation Analysis of the Impact of Energy-Saving Technologies on Enterprise Business Processes

Pearson's Correlations								
Variable			Technologies for optimising energy consumption	Energy efficient materials	Combined heat and power generation	Cogeneration of electricity, heat and cold	Replacing energy-intensive outdated equipment	Installation of industrial voltage regulators
Key business processes	Pearson's r		-0.212	0.050	-0.033	0.229	0.085	-0.209
	p-value		0.320	0.816	0.879	0.283	0.693	0.326
Ancillary business processes	Servicing business processes	Pearson's r	0.144	-0.145	0.027	0.198	**-0.303**	-0.267
		p-value	0.501	0.500	0.901	0.353	0.149	0.208
	Management business processes	Pearson's r	0.035	0.172	0.160	-0.221	-0.134	-0.028
		p-value	0.870	0.422	0.456	0.300	0.534	0.897
	Business development processes	Pearson's r	0.121	0.024	0.157	**-0.380**	**0.370**	0.196
		p-value	0.575	0.911	0.465	0.067	0.075	0.358

Source: compiled by the author based on the results of correlation analysis

During the correlation analysis, the highest degree of influence was observed in the cogeneration of electricity on auxiliary business development processes ($r = -0.38$; $p = 0.067$) and the replacement of energy-intensive outdated equipment on servicing business processes ($r = -0.3$; $p = 0.15$) and business development processes ($r = -0.37$; $p = 0.08$), indicating a statistically significant correlation between the identified technologies and corresponding business processes. Thus, with the increasing use of cogeneration of

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electricity and the replacement of energy-intensive equipment in enterprises, a favourable environment is formed for reducing energy and overall resource costs and increasing the productivity of business processes.

Conclusions

Today, energy-saving technologies play one of the most critical roles in transforming business processes towards increasing efficiency and sustainability. The conducted study showed that the implementation of energy consumption optimisation technologies (75.25), combined heat and power production (76.67), and energy-efficient materials (78.3) significantly reduces energy costs and consumption volumes, as well as ensures the long-term sustainability of production processes. According to the results of the correlation analysis, a significant impact of cogeneration of electricity on business development processes ($r = -0.38$; $p = 0.067$) and the replacement of energy-intensive outdated equipment on servicing business processes ($r = -0.3$; $p = 0.15$) was revealed, underscoring the importance of these technologies for increasing the overall efficiency of enterprises. Therefore, energy-saving technologies should be widely implemented at the state level to develop green entrepreneurship and energy-efficient programs.

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