GRASSROOTS JOURNALS

Grassroots Journal of Natural Resources, Vol.8 No.1 (April 2025)
ISSN: 2581-6853 | CODEN: GJNRA9 | Published by The Grassroots Institute
Website: https://grassrootsjournals.org/gjnr | Main Indexing: Scopus and WoS

ISSN 2581-6853 | 8(1) April 2025

M – 00492 | Review & Analytical Article

Energy-Saving Technologies and Innovations: Driving Competitiveness in Contemporary Business

Nataliia Gavkalova*[1], Svitlana Smereka[2], Iryna Kadyrus[3], Serhiy Kyrylenko[4], Maryna Kasatkina[5]

[1]Department of Public Administration & Economic Policy, Simon Kuznets Kharkiv National University of Economics, Kharkiv, Ukraine. Email: gavkalova@gmail.com | ORCID: https://orcid.org/0000-0003-1208-9607

[2]Department of Entrepreneurship & Trade, West Ukrainian National University, Ternopil, Ukraine. Email: smereka.svitlana.2017@gmail.com | ORCID: https://orcid.org/0000-0002-8854-885X

[3]Department of Marketing, Dnipro States Agrarian and Economic University, Dnipro, Ukraine. Email: kadyrus.i.h@dsau.dp.ua | ORCID: https://orcid.org/0000-0002-5024-6549

[4]Department of Entrepreneurship & Trade, West Ukrainian National University, Ternopil, Ukraine. Email: serhiy.kyrylenko@gmail.com | ORCID: https://orcid.org/0000-0002-7804-0403

[5]Department of Economics & Entrepreneurship, Volodymyr Dahl East Ukrainian National University, Kyiv, Ukraine. Email: the.markas80@gmail.com | ORCID: https://orcid.org/0000-0002-7053-1232

**Corresponding author*

How to cite this paper: Gavkalova, N., Smereka, S., Kadyrus, I., Kyrylenko, S. and Kasatkina, M. (2025). Energy-Saving Technologies and Innovations: Driving Competitiveness in Contemporary Business. *Grassroots Journal of Natural Resources*, 8(1): 138-162. Doi: https://doi.org/10.33002/nr2581.6853.080105

Received: 24 January 2025
Reviewed: 07 March 2025
Provisionally Accepted: 13 March 2025
Revised: 28 March 2025
Finally Accepted: 31 March 2025
Published: 09 April 2025

Abstract

This study examines how innovations and energy-saving technologies contribute to the long-term competitiveness of Ukrainian businesses in the current environment. The study employs various scientific methods, including literature synthesis, statistical analysis, systematisation, and generalisation, to identify key challenges and opportunities for introducing innovations and energy-saving technologies to modern enterprises. Findings indicate significant disparities in innovation activity across industries. The manufacturing sector leads in innovation (Mean = 313.75, SD = 161.56), while the extractive industry (Mean = 5.5, SD ≈ 4.2) and electricity supply sector (Mean = 4, SD ≈ 0.82) show minimal engagement. Additionally, sales of innovative products exhibit high variability (CV = 2) in the extractive, electricity supply, and water supply industries, reflecting instability caused by price fluctuations and war-related disruptions. Despite these challenges, industrial enterprises exporting innovative products outside Ukraine demonstrate strong potential for innovation-driven growth (Mean = 15,311,932.5). The study confirms that innovation, particularly energy-saving technologies, plays a crucial role in enhancing business competitiveness by improving production efficiency and sustainability. However, it also identified barriers to innovation activity in Ukraine, including uneven development across industries. Addressing these challenges through targeted policies and investment in energy-efficient solutions can foster a more resilient and competitive business environment in Ukraine. However, it also identified obstacles to innovation in Ukraine, including uneven sector development, geopolitical instability, and energy efficiency. These challenges require targeted policy measures aimed at stimulating innovation in underdeveloped sectors, improving energy security, and increasing resilience to external shocks.

Keywords

Innovations; Innovation parks; Ukrainian Businesses, Energy Efficiency; Sustainable Development; Competitiveness

Doi: https://doi.org/10.33002/nr2581.6853.080105 Open Access

Introduction

In today's economy, innovation and energy-saving technologies play a critical role in driving economic growth, reshaping business processes, and promoting sustainable development amid global environmental challenges and increasing competition. Modern research emphasises that innovation contributes to both adaptation to dynamic market changes and the creation of sustainable competitive advantages by increasing operational efficiency, aligning businesses with global environmental standards, and attracting investment in emerging technologies (Daraojimba *et al*., 2023; Sahani, 2025; Stoliarchuk *et al*., 2022; Zahrebelna *et al*., 2024). Modern successful cases of Ukrainian enterprises that have successfully implemented energy-saving technologies to increase competitiveness indicate the prospects for transforming the structure of business processes and ensuring sustainable development of enterprises in the face of global environmental challenges and increasing competition. Furthermore, the agricultural enterprise "Smila" (Cherkasy region) successfully implemented a biogas plant that allows processing organic waste of animal origin and generating electricity and heat. Thanks to this, the enterprise reduced energy supply costs by 60%, sells surplus electricity at a "green tariff," and uses organic fertilizers to increase the productivity of the base. Vinnytsia Poultry Farm (MHP) launched one of the world's largest biogas plants operating on a chicken experiment, generating electricity and heat. The "Biohaz Ladyzhyn" complex annually reduces CO_2 emissions by 100000 tons, reduces environmental risks, and promotes sustainable development by using household products as organic fertilizers. These cases illustrate that investments in energy efficiency are strategically justified, contribute to reducing operating expenses, and create long-term competitive advantages, which are key factors in the successful integration of Ukrainian business into the global economy (GIZ, 2024).

Despite the high initial costs associated with implementing energy-saving technologies, their long-term benefits — such as reduced operational expenses and increased profitability — justify the financial investment (Desyatnyuk *et al*., 2024; Gennitsaris *et al*., 2023; Hudyma, 2024; Kyrylenko *et al*., 2022; Zhang, Yang and Liu, 2022). According to Gavkalova *et al*. (2024), integrating environmentally sustainable technologies is essential due to increasing material intensity and inefficient resource management, which contribute to environmental degradation, resource depletion, declining enterprise efficiency, and reduced product quality. The latest report from the International Renewable Energy Agency (IRENA, 2024), indicates that global renewable energy capacity reached a record of 473 GW last year, with 81% of newly commissioned large-scale renewable energy projects being more cost-effective than fossil fuel alternatives, even as fossil fuel prices returned to historical cost levels following the 2022 energy crisis. Given that in 2024, Ukraine increased electricity imports to 4.4 million MWh, which is 5.5 times more than in the previous year (ExPro, 2024), it is becoming increasingly important to find ways to implement the latest solutions for Ukrainian businesses to overcome the challenges of war and the post-war period. Therefore, intensifying innovation and implementing energy-saving technologies are strategically important to ensure sustainable development, increase international competitiveness, and integrate business into the European and global economic areas.

This article aims to identify key prospects and barriers to enhancing innovation and integration of energy-saving technologies into business operations. It also aims to study the role of innovations and energy-saving technologies in ensuring the long-term competitive advantage of Ukrainian businesses in today's economic and regulatory landscape. To determine the impact of innovations and energy-efficient technologies on business competitiveness, the study uses a combination of general scientific research methods and a quantitative approach to assess the financial and operational performance of enterprises implementing these technologies.

Literature Review

Considering the factors of success of enterprises in the context of globalisation and growing international competition, modern scholars identify innovation and the introduction of energy-saving technologies as the key drivers of competitiveness. Innovations allow enterprises to adapt to rapid changes in market conditions, enhance product quality, reduce costs, and create new customer segments (Adama and Okeke, 2024; Daraojimba *et al*., 2023; Khaminich *et al*., 2020; Niziaieva *et al*., 2022; Sudirjo, 2023). Other studies, such as Lin and Huang (2023) and Sahoo and Lo (2022), emphasise the need to modernise production processes, including automation, digital technology integration and renewable energy sources. However, as Dacre *et al*. (2024) point out, an overemphasis on technology can lead to a neglect of other important aspects of business, such as customer relations and employee engagement. While several authors, including Bravo and Iturralde (2022) and Gorina *et al*. (2024) support the integration of renewable and energy-saving technologies as part of sustainable business development strategies, given the dependence of enterprises on traditional energy sources and global climate change trends, others note the high cost of implementing energy-saving technologies such as solar panels, heat recovery systems, heat pumps that may be unaffordable for SMEs for a long time (Gennitsaris *et al*., 2023; Schmitka and Endzejczyk, 2020; Tazhibekova and Shametova, 2024). Another important finding of Kovalko, Eutukhova and Novoseltsev (2022) is the need to implement mechanisms for cooperation between innovative companies for large-scale implementation of measures in the field of energy efficiency and renewable energy sources. In this context, the study by Mironova *et al*. (2022) on the implementation of innovation strategies at industrial enterprises in Poland showed that, with maximum support from the state and private investors, it is important to develop an innovation project by intensifying cooperation with participants in an industrial or regional cluster or innovation park. Instead, Qiao *et al*. (2022) approach this issue from a regulatory perspective, emphasizing that strengthening environmental regulation is crucial for addressing energy and environmental challenges while improving legal norms for factor pricing. Considering innovation in general, Krysovatyy and Ptashchenko (2023) emphasize the need to strengthen and expand the regulatory framework for various research and innovation-related issues. However, despite the potential challenges of modern businesses using energy-saving technologies, opportunities play a more significant role in the further development of the business sector. Thus, among the benefits of introducing energy-efficient technologies in the scientific literature are the following: reduced operating costs and, as a result, increased business profitability (Hudyma, 2024; Kyrylenko *et al*., 2022); further intensification of environmental development by increasing competitiveness (Sotnyk *et al*., 2023; Yayha *et al*., 2024); alignment of the enterprise's market goal with global sustainable

development goals, which will help attract environmentally conscious consumers (Druhova *et al*., 2024). To summarise the benefits, it is important to note the role of innovation in ensuring business competitiveness in general. Thus, given that modern enterprises face challenges associated with rapid technological progress and market volatility, the integration of innovative solutions and energy-saving technologies becomes important for maintaining competitive advantage (Sahani, 2025); potential increase in productivity and operational efficiency, which allows enterprises to reduce costs and improve product quality (Stoliarchuk *et al*, 2022; Zahrebelna *et al*., 2024); ensuring market adaptability of business through the introduction of new technological advances, including AI and IoT (Ostapchuk and Mykolaichuk, 2024; Segun-Falade *et al*., 2024). Despite the recognized role of innovation and energy-saving technologies in business competitiveness, key gaps should be noted: first, while digitalization and renewable energy integration are widely promoted (Lin and Huang, 2023; Sahoo and Lo, 2022), research lacks empirical evidence on their long-term financial viability, especially for SMEs that face high implementation costs (Gennitsaris *et al*., 2023; Tazhibekova and Shametova, 2024); second, Dacre *et al*. (2024) highlight the risk of over-reliance on technology at the expense of human capital, but research does not fully explore strategies for balancing innovation with workforce engagement; third, the effectiveness of industrial clusters and innovation parks in promoting energy efficiency (Kovalko, Eutukhova and Novoseltsev, 2022; Mironova *et al*., 2022) remains understudied, as existing studies ignore regulatory and financial barriers. Therefore, further research is needed to assess the real impact of regulations and cooperation models on business efficiency.

Methodology

This study employed the synthesis method of literature review to identify key theoretical aspects and factors enhancing modern business competitiveness, with a focus on innovation and energy-saving technologies. Based on the statistical data analysis, the article describes the main challenges to competitiveness and barriers to the functioning of modern businesses when implementing innovations. The systematisation method was applied to study the potential risks of the impact of the identified barriers on the competitiveness of businesses engaged in innovative activities in the current market conditions.

To conduct a quantitative study on the impact of innovation on the competitiveness of modern enterprises, we analysed official statistics from the State Statistics Service of Ukraine on the number of industrial enterprises and the volume of innovative industrial products (goods, services) sold by such enterprises in 2020-2023 (see Appendix-1). Enterprises were categorised into groups by type of economic activity. The choice of this period for the analysis is justified by the need to analyse the possibilities of intensifying innovation activities to increase the competitiveness of Ukrainian industrial enterprises in the context of the pandemic and after the start of Russia's full-scale invasion. This timeframe was chosen not only due to the pandemic and wartime disruptions but also to capture the evolving trends in innovation adoption under extreme economic conditions, such as shifting investment priorities, policy interventions, and structural transformations in key industries. Moreover, this period reflects the first

significant adjustments to Ukraine's innovation policy in response to global sustainability commitments and EU integration efforts.

Despite the relevance of this period, certain limitations should be acknowledged. In particular, data collection failures during wartime may lead to inconsistent or missing values, potentially affecting the accuracy of trend estimates. The selected time frame may be too short to observe the full effects of innovation-driven transformation, especially for capital-intensive industries. Potential biases arise from variations in regional economic resilience, as some regions face greater infrastructural and financial constraints, which impact the overall innovation landscape.

To perform descriptive statistics on these indicators, the key statistical characteristics were calculated:

First of all, to determine the overall level of innovation activity of enterprises by type of economic activity, we calculated the average values (Mean) for each indicator using the following formula:

$$\overline{X} = \frac{\sum_{i=1}^{n} X_i}{n} \quad (1)$$

where X_i is the value of the indicator for each type of economic activity;
n is the number of periods.

The next step is to calculate the median, defined as the average value of the central element of an ordered series. The median value indicates the level of the indicator located in the middle of the sample and indicates trends in the average activity of enterprises. The MEDIAN function of the Excel analysis package was used to calculate this indicator.

Next, to disperse the values of the indicators around the mean value, we calculated the variance for each indicator using the following formula:

$$(X) = \frac{\sum_{i=1}^{n} (X_i - \overline{X})}{n - 1} \quad (2)$$

where $\overline{X}$ is the average value.

To determine the degree of fluctuation around the mean for each indicator, the standard deviation (SD) was calculated using the following formula:

$$D(X) = \sqrt{\mathrm{Var}(X)} \quad (3)$$

In the course of calculations, it is also important to determine the coefficients of variation (CV), mainly to assess each indicator's relative level of variability. The formula for calculating the coefficient of variation is as follows:

$$(X) = \frac{SD(X)}{\bar{X}} * 100\% \quad (4)$$

In addition, to analyse each indicator's boundaries, we calculated its minimum and maximum level for each type of activity using the Excel analysis package's MIN and MAX functions.

To visualise the results, a scatter plot of mean values and standard deviations was developed to assess the general trends in the innovation activity of entities in various types of economic activity. The study's key conclusions and prospects for further development of the discussion on the competitiveness of modern business in the context of the development of innovations and energy-saving technologies were formed by the generalisation method.

Table 1: Examples of successful integration of biogas technologies into agriculture

Company	*Region*	*Source of raw materials*	*Operating principle*	*Key results*
Agricultural firm "Smila"	Cherkasy region	Animal manure, plant waste, corn silage	Anaerobic fermentation, biogas purification, electricity and heat production	Reduction of energy supply costs by 60%, sale of excess electricity at a "green tariff", use of digestate as fertilizer
MKhP (Vinnytsia Poultry Farm)	Vinnytsia region	Chicken manure	Processing in fermenters, generation of electricity and heat, use of organic residue as fertilizer	Reduction of CO^2 emissions by 100 thousand tons per year, ensuring the energy needs of the factory and surrounding areas, and ecological waste disposal
Hals Ahro	Kyiv and Chernihiv regions	Sugar beet pulp, molasses, silage, animal manure	Anaerobic digestion, biogas production, cogeneration, biomethane production	Biomethane generation (3 million m^3 per year), reducing dependence on natural gas, using European membrane purification technologies
GoodValley Ukraine ("Danosha")	Ivano-Frankivsk region	Pig farm waste, plant residues	Anaerobic digestion, biogas production, cogeneration	Self-sufficiency in electricity, reduction of greenhouse gas emissions, and improvement of the ecological state of the region

Source: GIZ (2024)

Results

The role of innovations in ensuring business competitiveness is one of the key aspects of modern economic development, reflecting the need for companies to adapt to dynamic market conditions and global challenges. Innovations help increase production processes' efficiency, expand sales markets, improve product quality and create new business models that meet modern environmental and social standards. Of particular importance in this context is the introduction of energy-saving technologies, which, according to the International Energy Agency (IEA) report, have a positive

macroeconomic impact, stimulate economic activity, increase productivity by reducing maintenance problems and optimising processes, bring financial benefits to government budgets through increased revenues and reduced costs, and reduce the business sector's dependence on energy imports and the risk of supply disruptions (IEA, 2019, 2023).

The integration of renewable energy sources into the agricultural sector is one of the key areas of development of modern agriculture, which contributes to increasing energy efficiency, reducing greenhouse gas emissions, and implementing the principles of a circular economy. The use of biogas plants allows agricultural enterprises to effectively utilize organic waste, obtaining additional energy sources for their needs and sales at a "green tariff". The table 1 provides a case analysis of successful Ukrainian agricultural enterprises that have implemented biogas technologies, ensuring sustainable development and economic benefit.

The use of biogas technologies in agriculture is an important step towards ecological modernization and energy independence of agricultural enterprises. The considered cases demonstrate that biogas plants allow not only to effectively utilize organic waste, but also contribute to reducing production costs, reducing greenhouse gas emissions, and increasing environmental safety. Such experience indicates the prospects for the further development of bioenergy in the agricultural sector and its importance for ensuring sustainable development.

The prospect of developing energy-saving technologies is explained by their central position in reducing the energy intensity of the economy and minimising the environmental impact. According to the IEA's Clean Energy Progress Tracking Report (2023), a wide range of technologies and measures, such as electrification, digitalisation, behavioural change and rational use of materials, are essential to achieve the required 4% annual increase in energy intensity. For example, in 2022, the total final energy consumption was about 440 EJ, with 38% used by industry, followed by infrastructure (30%) and transport (26%). Therefore, energy-saving technologies, as one of the key components of overall energy efficiency in the long run, will reduce dependence on traditional energy sources and stabilise (and in the best-case scenario, reduce) energy consumption, which is especially important in the context of achieving the net-zero emissions scenario by 2050. The IEA's findings underline the critical importance of such technologies for sustainable economic growth in both the business segment and global CO_2 emissions reduction. Based on the preliminary literature analysis, the key benefits of implementing energy-saving technologies as a strategic solution for modern business aimed at long-term development and sustainability were identified, as shown schematically in figure 1.

Thus, to increase the stability and efficiency of innovations in foreign markets, Ukrainian enterprises must focus on developing their innovation potential, introducing energy-saving technologies and increasing competitiveness, which is especially important in the current business environment. However, according to a survey conducted by the National IP&I Hub in 2024, there are currently several significant barriers to innovation in enterprises that most restrict innovation development in Ukraine. The detailed analytics based on the survey results consist of two main blocks, including internal and legal barriers to business, as shown in figure 2.

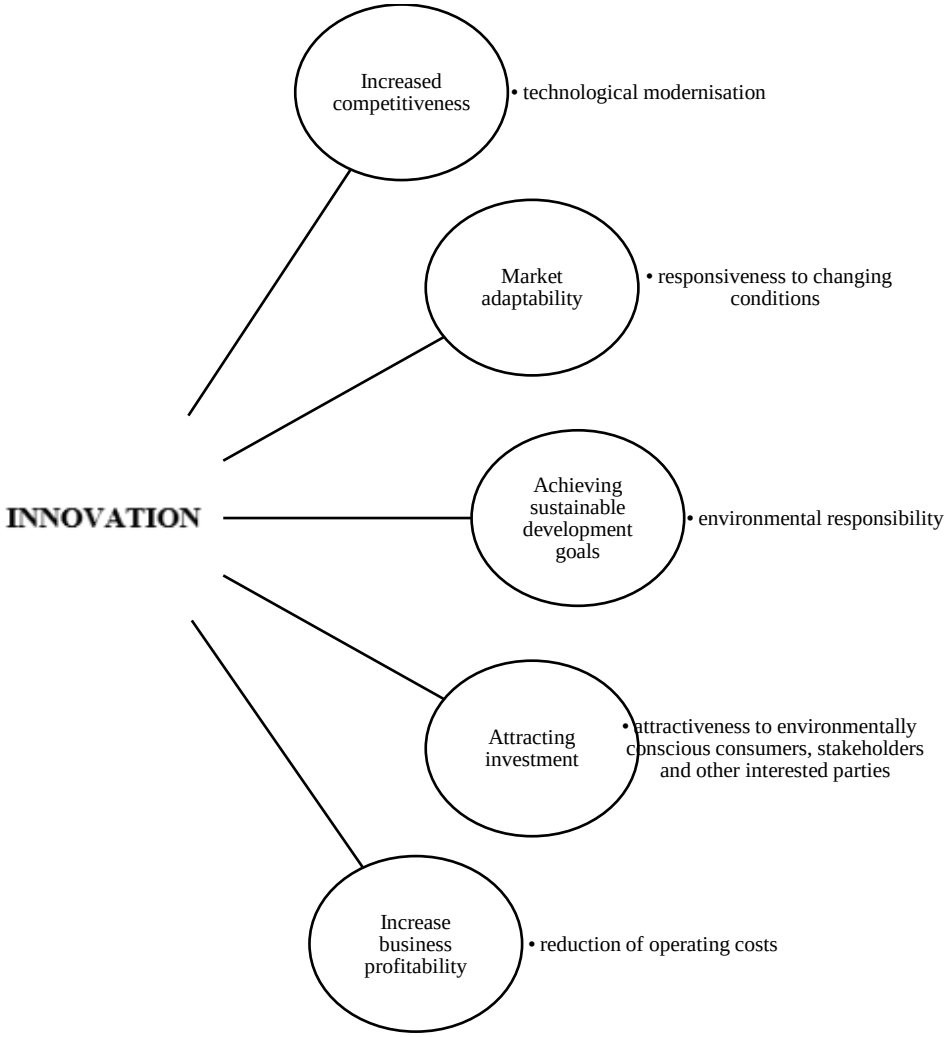
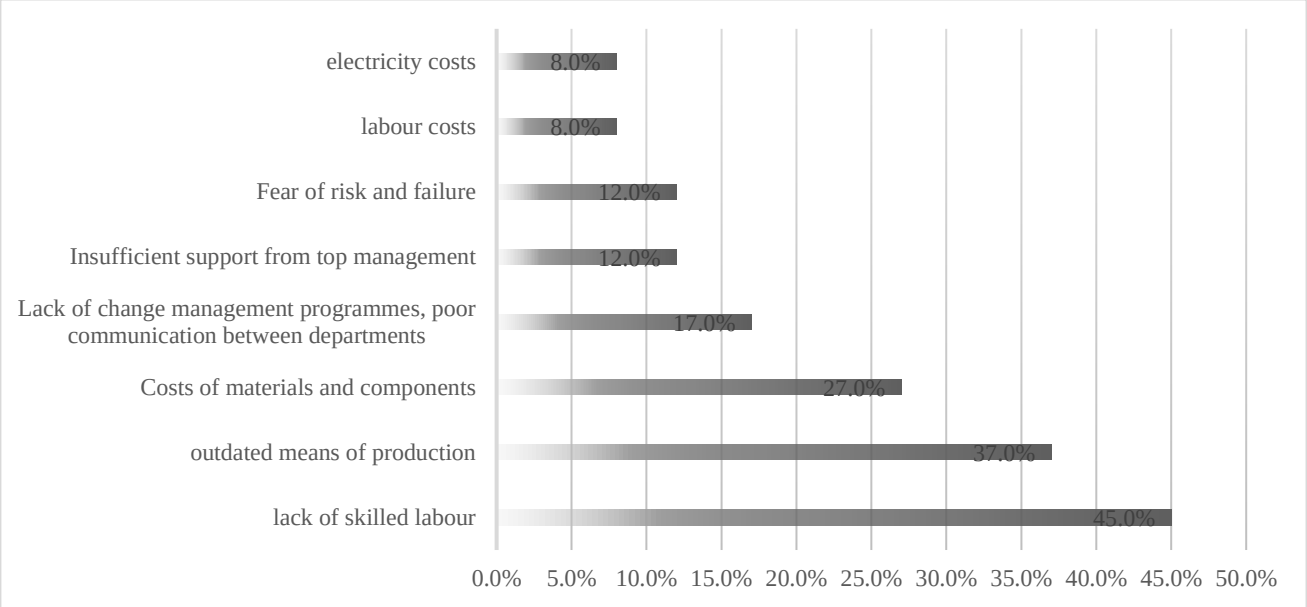


Figure 1: Prospects for introducing innovations and energy-saving

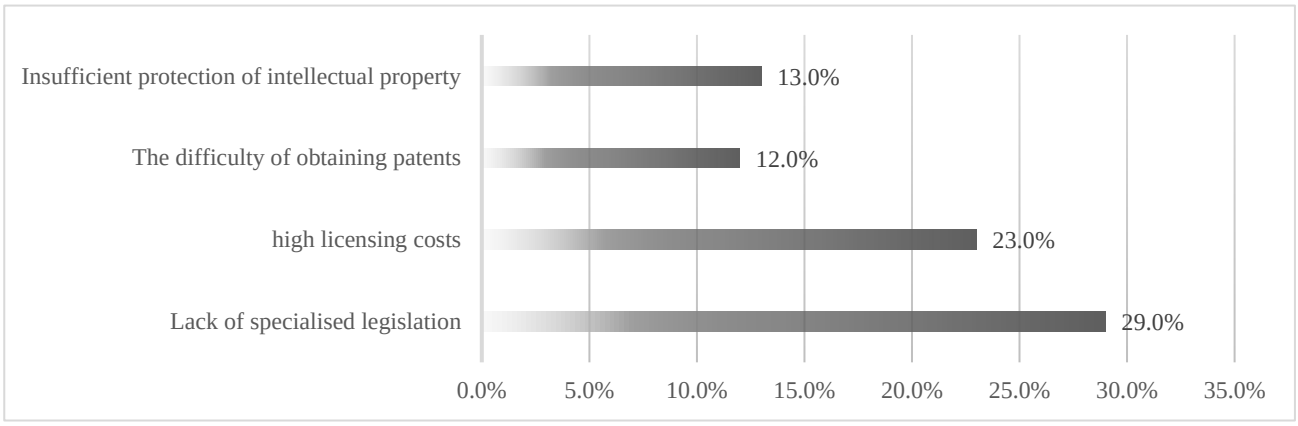
Addressing these challenges is particularly important for Ukrainian enterprises, which operate under persistent economic, political, and military crises that significantly hinder innovation competitiveness. Given the ongoing crisis and war-related consequences, along with globalization, Ukraine's transition to an innovative economy is expected to take longer. Therefore, the adaptive capacities at the microeconomic level are essential, as enterprises serve as key testing grounds for technological innovations and the commercialization of the latest scientific and technical developments (Kyrylenko *et al*., 2022).

In justifying the choice of the research object, it is important to highlight those large industrial enterprises, unlike other microeconomic entities, generate more financial, material and other resources, have the potential to introduce fundamental innovations and act as a driver of innovative development at the state level. According to the State Statistics Service (2023), the number of entirely new products (goods, services) on the market is currently 27.45% (UAH 5320187 thousand) of the total sales (19381815 thousand) in the industrial sector of Ukraine's economy. At the same time, a significant portion of modern enterprises' expenditures on innovation is directed to the purchase of

new machinery, equipment, and software (Stoliarchuk *et al*., 2022). This trend suggests that enterprises are prioritizing modernization to enhance production efficiency and strengthen competitiveness in international markets. Given this, analyzing the dynamics of innovation activity in modern industrial enterprises is essential. To begin, we calculated key statistical characteristics of the number of industrial enterprises that sold innovative products between 2020 and 2023 (Table 2).



a) Internal barriers to innovation in enterprises



b) Legal barriers to innovation in enterprises

Figure 2: Key barriers to innovation [*Source:* IP Office (2024)]

Doi: https://doi.org/10.33002/nr2581.6853.080105 Open Access

Table 2: Key statistical characteristics of the number of industrial enterprises that sold innovative products (goods, services) by type of economic activity in 2020–2023

Types of economic activity	*Descriptive statistics*						
	Mean	*Median*	*Variance*	*Standard Deviation (SD)*	*Min*	*Max*	*Coefficient of Variation (CV), %*
Industry	326.25	248	27094.91	164.60	236	573	0.50
Mining and quarrying	5.5	5	17.66	4.20	1	11	0.76
Processing industry	313.75	235	26100.91	161.55	229	556	0.51
Supply of electricity, gas, steam and air conditioning	4	4	0.66	0.81	3	5	0.20
Water supply, sewerage, waste management	3	2.5	4.66	2.16	1	6	0.72

Source: Derzhstat (2023)

Table 3: Statistical indicators of the volume of innovative products (goods, services) sold by enterprises within Ukraine by type of economic activity in 2020–2023

Types of economic activity	*Descriptive statistics*						
	Mean	*Median*	*Variance*	*SD*	*Min*	*Max*	*CV, %*
Industry	33856239.7	34258473	1.36671	11690627	19381815	47526197	0.345302
Mining and quarrying	1454458.3	0	8.4618	2908917	0	5817833	2
Processing industry	26324816	22276934	1.05057	10249712	19206936	41538460	0.389356
food production	3971159.5	3806017	1.59564	1263185	2609432	5663172	0.31809
beverage production	1936579	1949459	1.63858	1280070	675554	3171844	0.660996
textile production	27568.25	0	3040033632	55136.5	0	110273	2
Woodworking and manufacture of wood and cork products, except furniture; manufacture of straw and plant materials for weaving	434132.98	236535.5	3.55415E+11	596166.6	0	1263461	1.373235
production of paper and paper products	152773.73	175907	12376362305	111249.1	0	259281	0.728195
production of chemicals and chemical products	308768.84	217901.2	53791743651	231930.5	148455	650818	0.751146
production of basic pharmaceutical products and pharmaceuticals	851974.69	762711.9	1.76062	419597.6	443957	1438518	0.4925
manufacture of rubber and plastic products	152281.4	104351.8	29789300241	172595.8	0	400422	1.1334
Production of other non-metallic mineral products	560891.76	482083	2.00188	447423.3	103308	1176093	0.7977
Manufacture of fabricated metal products, except	967882.19	739511	2.72684	522191.6	598778	1565358	0.53952

Types of economic activity	*Descriptive statistics*						
	Mean	*Median*	*Variance*	*SD*	*Min*	*Max*	*CV, %*
machinery and equipment							
production of computers, electronic and optical products	798288.53	835239.6	1.92801	439090.7	229178	1293497	0.55004
production of electrical equipment	1179088.1	839236.2	7.57333	870248.7	595325	2442555	0.738069
Manufacture of machinery and equipment n.e.c.	2118203.3	2191205	1.74642	1321521	518867	3571537	0.623888
production of motor vehicles, trailers and semi-trailers	342589.94	150315.4	1.68642	410660.1	111802	957927	1.198693
production of other vehicles	2244572.7	2194224	2.28649	478172.5	1766022	2823821	0.213035
furniture production	118031.25	60848.5	14538671745	120576.4	51685	298743	1.021563
manufacture of other products	50821.884	24915.27	4826724676	69474.63	0	153457	1.367022
repair and installation of machinery and equipment	68102.7	31045.5	9845932998	99226.67	0	210319.8	1.457015
Supply of electricity, gas, steam and air conditioning	14240.351	0	811150386,4	28480.7	0	56961.4	2
Water supply, sewerage, waste management	3786.5	0	57350329	7573	0	15146	2

Source: Derzhstat (2023)

The analysis of key statistical characteristics of the number of industrial enterprises that sold innovative products revealed the dominant role of the manufacturing industry in implementing innovations, given the highest average (Mean = 313.75) with high variability (SD = 161.56). This is largely due to the significant number of enterprises focused on producing value-added products. At the same time, the level of innovation activity in the extractive industry (Mean = 5.5; SD ≈ 4.2) and electricity supply (Mean = 4; SD ≈ 0.82) is much lower, indicating a potential reserve for the introduction of innovative technologies. Notably, the water supply and waste management sector has the highest coefficient of variation (CV ≈ 72%), signalling market instability and a need for enterprise modernization. The identified trends highlight the importance of enhanced government regulation to address disparities in innovation activity across industries, particularly in sectors with low adoption rates. The next stage of the study is to calculate the volume of innovative products (goods, services) sold by enterprises within Ukraine (Table 3) and abroad (Table 4).

The results reveal significant differences in innovation activity across economic sectors. These variations are likely driven by global mineral price volatility and supply chain disruptions caused by the war, affecting both supply stability and raw material pricing. The mining industry, in particular, has a low mean value (Mean = 1454458.3) and a very high

coefficient of variation (CV = 2), indicating substantial fluctuations in economic performance. These variations are likely driven by global mineral price volatility and supply chain disruptions caused by the war, affecting both supply stability and raw material pricing. Across the industry, the average number of firms introducing innovative products (Mean = 326.25) reflects relatively high innovation activity. However, the high standard deviation (SD = 164.61) suggests considerable variability among firms, which may stem from differences in resource availability, technological advancement, or strategic priorities. To visualise these findings, a scatter plot illustrating the mean values and standard deviations for various economic sectors is presented in figure 3.

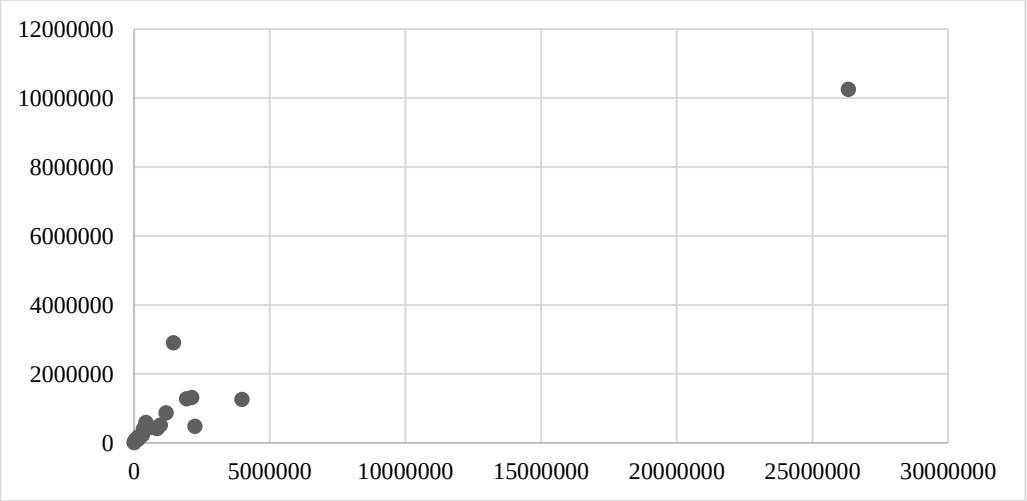


Figure 3: Scatter plot of mean values and standard deviations for different types of economic activity

Most economic sectors exhibit a low mean value and a slight standard deviation, indicating low variability and stable innovation activity among enterprises in the sample. However, the manufacturing industry stands out with a higher mean (Mean = 26,324,816) and standard deviation (SD = 11,690,627), suggesting greater fluctuations and less stability in innovation activity compared to other sectors. Overall, these findings indicate the relative stability of innovation activity across most industries. To gain a more comprehensive understanding of industrial enterprises' innovation dynamics in Ukraine, it is essential to analyze the statistical indicators of the volume of innovative products sold by manufacturing enterprises abroad (Table 4).

Geopolitical and economic challenges currently hinder Ukrainian enterprises from selling innovative products outside the country. It is accompanied by variability of indicators for different sectors of economic activity, which indicates the ambiguous nature of the development of innovation activity in foreign markets. In general, the average value of sales of innovative products by industrial enterprises (Mean = 15311932.5) indicates a predominantly export-oriented activity, but fluctuations in demand, currency instability, and supply chain disruptions due to the war result in a high standard deviation (SD = 19019635.87) and coefficient of variation (CV≈ 1.24) indicating significant volatility in international sales.

Table 4: Statistical indicators of the volume of innovative products (goods, services) sold by enterprises outside Ukraine by type of economic activity in 2021 and 2023

Types of economic	*Descriptive statistics*						
	Mean	*Median*	*Variance*	*SD*	*Min*	*Max*	*CV, %*
Industry	15311932.5	15311932.5	3.61747	19019635.87	1863019.0	28760846.0	1.242144705
beverage production	13003	13003.0	338156018	18389.01895	0	26006.0	1.414213562
production of chemicals and chemical products	18669	18669.0	88471602	9405.934403	12018.0	25320.0	0.503826365
production of electrical equipment	65967	65967.0	8703290178	93291.42607	0	131934.0	1.414213562
production of other vehicles	384669.5	384669.5	2.95941	544004.8239	0	769339.0	1.414213562
furniture production	23433.5	23433.5	1098257845	33139.97351	0	46867.0	1.414213562

Source: Derzhstat (2023)

Discussion

The results of the study confirmed that the manufacturing industry exhibits the highest level of innovation activity among all economic sectors (Mean = 313.75; SD = 161.56), aligning with the findings of Daraojimba *et al*. (2023), Adama and Okeke (2024) on the importance of innovation in creating value-added products. However, the low level of innovation activity in the extractive industry (Mean = 5.5; SD ≈ 4.2) and electricity supply (Mean = 4; SD ≈ 0.82) indicates that there is room for integration of energy-saving technologies, which is consistent with the findings of Lin and Huang (2023) on the need to modernise production processes. The average number of enterprises introducing innovative products was 326.25 (SD = 164.61), which indicates high but heterogeneous innovation activity. The variability of these indicators is explained by uneven access to resources, which confirms the findings of Sudirjo (2023) about the difference in strategic priorities of enterprises depending on their size and industry. Qiao *et al*. (2022) identified capital and labor price distortions as key obstacles to innovation efficiency in China's energy sector. However, while China's economic transformation differs from Ukraine's, our study found that the water supply and waste management sector has the highest coefficient of variation (CV ≈ 72%), indicating instability and the need for government intervention to modernize enterprises. The benefits of introducing innovative and energy-saving technologies identified in our study include reduced operating costs and increased business profitability, which confirms the previous findings of Hudyma (2024) and Kyrylenko *et al*. (2022). Furthermore, the results demonstrate that integrating renewable energy sources aligns with global sustainability goals, contributing to the attraction of environmentally conscious consumers, as Yayha *et al*. (2024) noted.

The instability of innovation activity in Ukraine’s mining and manufacturing sectors necessitates targeted policy interventions to enhance modernization and competitiveness (Milakovsky and Vlasiuk, 2024). The findings indicate significant disparities in

innovation intensity, particularly in the extractive industry, where the adoption of advanced technologies remains critically low. This highlights the need for sector-specific incentives to stimulate technological upgrades, following the example of Germany, where tax benefits and subsidies have accelerated the transition to energy-efficient production (Böhringer *et al.*, 2020). Limited access to capital remains a fundamental barrier to innovation, particularly for small and medium-sized enterprises, which aligns with global patterns observed in industrial economies (Cervantes *et al*., 2023 Cervantes, 2024). South Korea's experience demonstrates the effectiveness of specialized financial instruments, such as state-backed innovation funds and low-interest credit lines, in fostering technological advancements in capital-intensive sectors (Kim and Heo, 2017). Applying similar mechanisms in Ukraine could enhance the financial capacity of enterprises to invest in modern production technologies.

Conclusion

The study's key findings show the dominant role of innovation in ensuring business competitiveness in the context of globalisation and rapid economic development, which requires adapting modern enterprises to dynamic market conditions and global challenges. This approach not only boosts production efficiency but also stabilizes energy consumption and reduces environmental impact — key factors in achieving sustainable development. An analysis of statistical data of Ukrainian industrial enterprises revealed significant differences in the levels of innovation activity of business entities in different sectors of the country's economy. According to the calculations, the manufacturing industry, in particular, is the most active in implementing innovations. In contrast, the mining industry and electricity supply industries show lower levels of innovation, highlighting development opportunities. The high variability of innovation indicators across sectors highlights the urgent need to strengthen regulatory policies to address imbalances and foster a more uniform innovation-driven economy. A well-structured innovation strategy — focusing on technological modernization, regulatory improvements, and market-driven commercialization — can mitigate both internal and legal constraints on innovation in Ukraine, particularly in the light of the ongoing crisis and the war's impact on industry and exports. Such actions will contribute to Ukrainian enterprises' long-term competitiveness in domestic and foreign markets, especially given its ambitions for integration into European markets

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Appendix-1

Baseline data for the analysis of the dynamics of innovation activity of industrial enterprises by type of economic activity in 2020–2023

Table A1: Number of industrial enterprises that sold innovative products (goods, services) by type of economic activity in 2020–2023

Types of economic activity	*Period*			
	2020	*2021*	*2022*	*2023*
Industry	*573*	*246*	*250*	*236*
Mining and quarrying	11	6	4	1
Mining of hard and brown coal	–	1	–	–
crude oil and natural gas production	2	1	–	–
mining of metal ores	2	2	3	–
Extraction of other minerals and quarrying	5	1	1	1
providing additional services in the mining industry and quarrying	2	1	–	–
Processing industry	556	231	239	229
food production	120	50		48
beverage production	21	10	10	9
production of tobacco products	1	–	–	–
textile production	9	3	3	2
clothing production	3	4	4	3
production of leather, leather goods and other materials	3	–	–	–
Woodworking and manufacture of wood and cork products, except furniture; manufacture of straw and plant materials for weaving	14	8	8	5
production of paper and paper products	9	2	5	5
printing activities, duplication of recorded information	2	1	1	1
production of coke and oil refining products	2	1	1	–
production of chemicals and chemical products	40	19	13	11
production of essential pharmaceutical products and pharmaceuticals	31	13	16	16
manufacture of rubber and plastic products	25	7	10	13
Production of other non-metallic mineral products	28	4	10	8
metallurgical production	15	3	5	4
Manufacture of fabricated metal products, except machinery and equipment	33	13	16	18
production of computers, electronic and optical products	34	16	16	18
production of electrical equipment	34	18	15	14
Manufacture of machinery and equipment n.e.c.	58	28	20	18
production of motor vehicles, trailers and semi-trailers	17	4	6	7
production of other vehicles	21	11	14	14
furniture production	16	8	8	8
manufacture of other products	12	6	4	4
repair and installation of machinery and equipment	8	2	4	3
Supply of electricity, gas, steam and air conditioning	5	3	4	4

supply of electricity, gas, steam and air conditioning	5	3	4	4
Water supply, sewerage, waste management	1	6	3	2
water intake, treatment and supply	1	–	2	1
Sewerage, wastewater disposal and treatment	–	1	–	–
Collection, treatment and disposal of waste; recovery of materials	–	5	1	1
Other waste management activities	–	–	–	–

Source: Derzhstat (2023)

Table A2: The volume of innovative industrial products (goods, services) sold by enterprises by type of economic activity in 2020-2023

Types of economic activity	*Period*			
	2020	*2021*	*2022*	*2023*
Industry	*47526197.0*	*36838397.4*	*31678549.2*	*19381815.0*
Mining and quarrying	5817833.0	c/c	0	0,0
Mining of hard and brown coal	-	c/c	0	0
crude oil and natural gas production	c/c	c/c	0	0
mining of metal ores	c/c	c/c	0	0
Extraction of other minerals and quarrying	c/c	c/c	0	0
Providing support services in the mining and quarrying industry	c/c	c/c	0	0
Processing industry	41538460.0	22651040.0	21902827.4	19206936.0
food production	5663172.0	2609432.0	3893075.9	3718958.0
beverage production	1000949.0	675554.0	2897968.8	3171844.0
production of tobacco products	c/c	–	0	0
textile production	110273.0	c/c	0	0
clothing production	c/c	c/c	0	0
production of leather, leather goods and other materials	c/c	–	0	0
Woodworking and manufacture of wood and cork products, except furniture; manufacture of straw and plant materials for weaving	473071.0	c/c	1263460.9	0
production of paper and paper products	149685.0	c/c	202128.9	259281.0
printing activities, duplication of recorded information	c/c	c/c	0	0
production of coke and oil refining products	c/c	c/c	0	0
production of chemicals and chemical products	650818.0	250789.0	185013.4	148455.0
production of basic pharmaceutical products and pharmaceuticals	1438518.0	443957.0	792200.8	733223.0
manufacture of rubber and plastic products	400422.0	c/c	106590.6	102113.0
Production of other non-metallic mineral products	1176093.0	103308.0	494038.1	470128.0
metallurgical production	c/c	c/c	0	0
Manufacture of fabricated metal products, except machinery and equipment	739511.0	598778.0	1565357.6	c/c

production of computers, electronic and optical products	1293497.0	229178.0	892480.1	777999.0
production of electrical equipment	2442555.0	1067131.0	611341.4	595325.0
Manufacture of machinery and equipment n.e.c.	3571537.0	2719665.0	1662744.3	518867.0
production of motor vehicles, trailers and semi-trailers	957927.0	111802.0	156769.7	143861.0
production of other vehicles	1953042.0	1766022.0	2823821.0	2435406.0
furniture production	298743.0	51685.0	63825.0	57872.0
manufacture of other products	153457.0	21672.0	28158.5	0
repair and installation of machinery and equipment	62091.0	c/c	210319.8	0
Supply of electricity, gas, steam and air conditioning	c/c	c/c	56961.4	0
supply of electricity, gas, steam and air conditioning	c/c	c/c	56961.4	0
Water supply, sewerage, waste management	c/c	15146.0	0	0
water intake, treatment and supply	c/c	–	0	0
Sewerage, wastewater disposal and treatment	-	c/c	0	0
Collection, treatment and disposal of waste; recovery of materials	-	c/c	0	0
Other waste management activities	–	–	0	0

Source: Derzhstat (2023)

Table A3: The volume of innovative industrial products (goods, services) sold by enterprises outside Ukraine by type of economic activity in 2021, 2023

Types of economic	*Period*	
	2021	*2023*
Industry	*28760846.0*	*1863019.0*
Mining and quarrying	c/c	–
Mining of hard and brown coal	–	–
crude oil and natural gas production	–	–
mining of metal ores	c/c	–
Extraction of other minerals and quarrying	c/c	–
Providing support services in the mining and quarrying industry	–	–
Processing industry	c/c	c/c
food production	c/c	c/c
beverage production	c/c	26006.0
production of tobacco products	–	–
textile production	c/c	–
clothing production	c/c	c/c
production of leather, leather goods and other materials	–	–
Woodworking and manufacture of wood and cork products, except furniture; manufacture of straw and plant materials for weaving	c/c	c/c

production of paper and paper products	c/c	c/c
printing activities, duplication of recorded information	c/c	–
production of coke and oil refining products	c/c	–
production of chemicals and chemical products	12018.0	25320.0
production of basic pharmaceutical products and pharmaceuticals	c/c	c/c
manufacture of rubber and plastic products	c/c	c/c
Production of other non-metallic mineral products	–	c/c
metallurgical production	c/c	c/c
Manufacture of fabricated metal products, except machinery and equipment	c/c	c/c
production of computers, electronic and optical products	c/c	c/c
production of electrical equipment	c/c	131934.0
Manufacture of machinery and equipment n.e.c.	c/c	c/c
production of motor vehicles, trailers and semi-trailers	–	c/c
production of other vehicles	769339.0	c/c
furniture production	c/c	46867.0
manufacture of other products	c/c	c/c
repair and installation of machinery and equipment	–	–
Supply of electricity, gas, steam and air conditioning	–	c/c
supply of electricity, gas, steam and air conditioning	–	c/c
Water supply, sewerage, waste management	–	–
water intake, treatment and supply	–	–
Sewerage, wastewater disposal and treatment	–	–
Collection, treatment and disposal of waste; recovery of materials	–	–
Other waste management activities	–	–

Source: Derzhstat (2023)

Authors' Declarations and Essential Ethical Compliances

Authors' Contributions (in accordance with ICMJE criteria for authorship)

Contribution	*Author 1*	*Author 2*	*Author 3*	*Author 4*	*Author 5*
Conceived and designed the research or analysis	Yes	No	Yes	Yes	No
Collected the data	Yes	No	Yes	No	Yes
Contributed to data analysis & interpretation	Yes	Yes	No	Yes	No
Wrote the article/paper	Yes	Yes	Yes	Yes	Yes
Critical revision of the article/paper	Yes	Yes	Yes	Yes	Yes
Editing of the article/paper	Yes	Yes	Yes	Yes	Yes
Supervision	No	Yes	No	Yes	Yes
Project Administration	Yes	No	No	No	No
Funding Acquisition	No	No	No	No	No
Overall Contribution Proportion (%)	20	20	20	20	20

Funding
No financial support was received for the research and writing of this article.

Research involving human bodies or organs or tissues (Helsinki Declaration)
The author(s) solemnly declare(s) that this research has not involved any human subject (body or organs) for experimentation. It was not a clinical research. The contexts of human population/participation were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of Helsinki Declaration does not apply in cases of this study or written work.

Research involving animals (ARRIVE Checklist)
The author(s) solemnly declare(s) that this research has not involved any animal subject (body or organs) for experimentation. The research was not based on laboratory experiment involving any kind animal. The contexts of animals were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or ethical obligation of ARRIVE does not apply in cases of this study or written work.

Research on Indigenous Peoples and/or Traditional Knowledge
The author(s) solemnly declare(s) that this research has not involved Indigenous Peoples as participants or respondents. The contexts of Indigenous Peoples or Indigenous Knowledge were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or prior informed consent (PIC) of the respondents or Self-Declaration in this regard does not apply in cases of this study or written work.

Research involving Plants
The author(s) solemnly declare(s) that this research has not involved the plants for experiment and field studies. Some contexts of plants are also indirectly covered through

literature review. Thus, during this research the author(s) obeyed the principles of the Convention on Biological Diversity and the Convention on the Trade in Endangered Species of Wild Fauna and Flora.

Research Involving Local Community Participants (Non-Indigenous) or Children
The author(s) solemnly declare(s) that this research has not directly involved any local community participants or respondents belonging to non-Indigenous peoples. Neither this study involved any child in any form directly. The contexts of different humans, people, populations, men/women/children and ethnic people were only indirectly covered through literature review. Therefore, an Ethical Clearance (from a Committee or Authority) or prior informed consent (PIC) of the respondents or Self-Declaration in this regard does not apply in cases of this study or written work.

PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses)
The author(s) has/have NOT complied with PRISMA standards. It is not relevant in case of this study or written work.

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During the preparation of this work, the authors used ChatGPT to assists the script translation and proof reading. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

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