UDC 330.341
DOI: 10.15587/1729-4061.2024.299654

MUTUAL INFLUENCE OF ENERGY EFFICIENCY AND INNOVATION ACTIVITY IN THE INDUSTRIAL SECTOR OF THE ECONOMY

Khanbibi Nursapina
Master of Economic Sciences, Senior Lecturer*
Tursynzada Kuangaliyeva
Candidate of Economic Sciences, Associate Professor, Head of School**
Aizhan Uryngaliyeva
Master of Economic Sciences, Senior Lecturer*
Nurkhat Ibadildin
Candidate of Technical Sciences, Associate Professor, Head of School**
Serik Serikbayev
Candidate of Economic Sciences, Senior Lecturer
Department of Business Technology
Al-Farabi Kazakh National University
al-Farabi ave., 71, Almaty, Republic of Kazakhstan, 050040
Ainagul Tulegenova
Master of Economic Sciences, Senior Lecturer
Department of Finance and Economics
West Kazakhstan Innovation and Technology University
N. Nazarbayev ave., 208, Uralsk, Republic of Kazakhstan, 09000
Zhaxat Kenzhin
Corresponding author
PhD Doctor, Associate Professor
Department of Social Humanities
Academy of Physical Education and Mass Sports
Mangilik el ave., EXPO business center, block B., Astana,
Republic of Kazakhstan, 010000
E-mail: jaksat_22@mail.ru
*Higher School Economics and Audit
Zhangir Khan University
Zhangir Khan str., 51, Uralsk, Republic of Kazakhstan, 090009
**School of Creative Industry
Astana IT University
Mangilik el ave., 55/11, EXPO Business center, block C 1, Astana,
Republic of Kazakhstan, 010000

The object of the study is energy efficiency and innovation activity of industrial enterprises.

The literature review has shown that the problem of the nature of mutual influence of energy efficiency and innovation activity of the enterprise remains unresolved. The following problem was investigated: existence and nature of dependence of energy efficiency and innovation activity of industrial enterprises. This problem is solved in this study based on the construction of trend lines on the average annual dynamics of changes in energy efficiency, the share of intangible assets and the share of R&D results of large industrial enterprises for 2018–2022. The following results were obtained:

– indicators of the share of intangible assets and R&D results directly affect the energy efficiency indicator;

– the indicator of energy efficiency does not affect the indicator of the share of intangible assets, while it has a direct impact on the indicator of R&D results.

These results explain the priority of the indicator "share of R&D results" in innovation activity for the energy efficiency of enterprises, as it is based on real production. The features of the obtained results consist in the application of comparable correlation analysis coefficients, confirming the existence of a direct relationship between these parameters. The paper provides recommendations on the use of the obtained results at the level of strategic management of an industrial enterprise.

The practical significance of this study is the possibility of applying the findings and recommendations to improve the energy efficiency of industrial enterprises in their innovative development in the scope and conditions corresponding to the developing economy

Keywords: energy efficiency, innovation activity, industrial enterprises, strategic management, correlation analysis

Received date 15.01.2024
Accepted date 22.03.2024
Published date 30.04.2024

How to Cite: *Nursapina, K., Kuangaliyeva, T., Uryngaliyeva, A., Ibadildin, N., Serikbayev, S., Tulegenova, A., Kenzhin, Z. (2024). Mutual influence of energy efficiency and innovation activity in the industrial sector of the economy. Eastern-European Journal of Enterprise Technologies, 2 (13 (128)), 6–14. doi: https://doi.org/10.15587/1729-4061.2024.299654*

1. Introduction

The development of any country's economy involves passing through certain stages: pre-industrial, industrial and post-industrial. The last few decades have been characterized by the formation of a global world economic system, which is often identified with innovative development. The latter, as applied to industry, implies continuous technological improvement in the sphere of production with an increase in added value. The theoretical foundations of the innovation economy were laid at the beginning of the last century [1], and already in the second half of the twentieth century in the developed countries the course on the formation of postindustrial society with a dominant sector of innovation economy was taken. In the XXI century, this direction has become relevant for newly independent states.

Against the background of modernization of young economies, there is an objective need to determine the strategic vector of innovative development. When choosing, it is important to take into account the large-scale problem, which requires some kind of unifying beginning in terms of satisfying the interests of the largest possible set of economic entities, as well as for the whole country. Increasing energy efficiency can act as such a system-forming vector. Intensive development in this case arises due to modernization of internal processes of energy resources consumption, coefficient of performance by increasing the efficiency factor. This is appropriate for all spheres of the economy, but the special need for energy in industry determines the relevance of such an innovative path in relation to this sector of the economy. Nevertheless, combining energy efficiency and innovation activities in a single vector of innovative development for a developing economy requires scientific justification.

OECD, IEA and other international authoritative organizations recognize energy efficiency improvement as an important direction for the development of national economies. Thus, the European Commission emphasizes the importance of improving energy efficiency as one of the main ways to address future challenges for both the EU countries and the Eastern Partnership countries [2, 3].

This direction is especially relevant for countries with high energy intensity of production (Fig. 1).

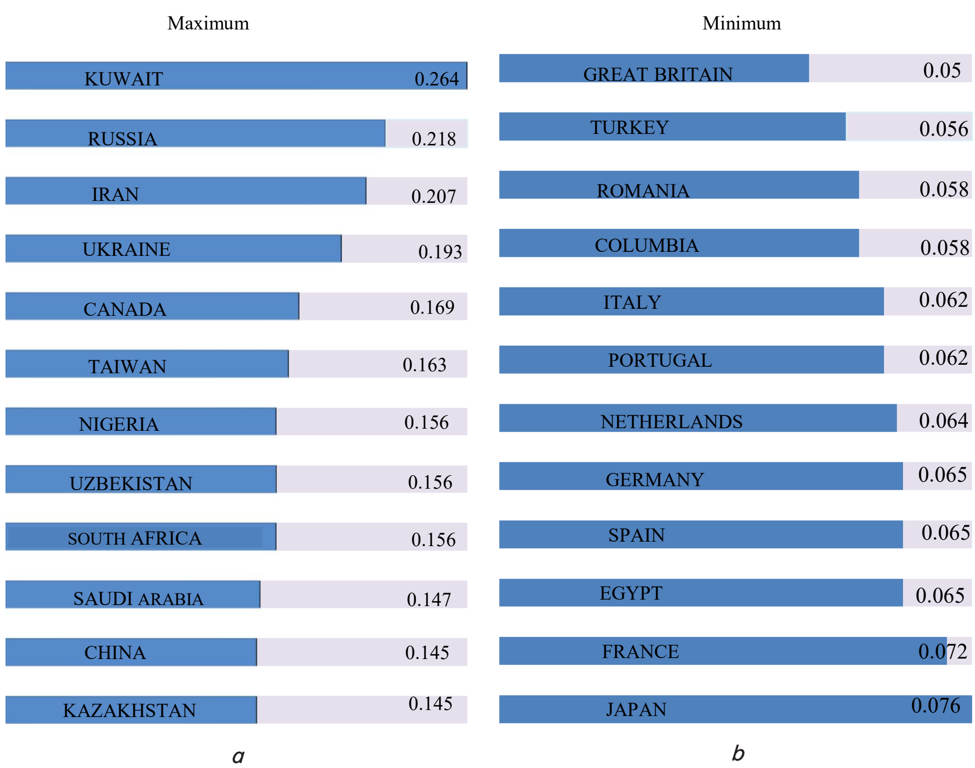

Fig. 1. The energy intensity indicator: *a* — maximum values; *b* — minimum values

In the case of the Republic of Kazakhstan, Uzbekistan and Ukraine, as newly independent states, this negative situation is due to the inherited Soviet experience of energy-intensive industries. The situation is different in the European Union, where the energy intensity per unit of GDP according to the data for 2022 is 42 % lower than the world average, largely due to the focus of roadmaps to improve energy efficiency ("Roadmap 2050", "Road Maps for Nanotechnology in Energy", "Multi-annual Roadmap", "The Energy-efficient Buildings", etc.) [4].

Toughening geopolitical rivalry in various areas, including the energy sector, poses a challenge to each state to overcome energy obstacles against the background of rising energy prices. Thus, energy efficiency is an important indicator of enterprise performance, especially for energy-intensive industrial production, but the question of its relationship with the innovation activity of the enterprise remains relevant. Therefore, the topic of the relationship between energy efficiency and innovation in the industrial sector of the economy is relevant.

2. Literature review and problem statement

The modern enterprise is characterized by a strategic focus on sustainable growth based on innovation to gain competitive advantage through the use of innovation. In the ordinary mind, innovation is understood only in the technological sense, and many enterprises follow this understanding. The paper [5] presents research proving that combining technological innovation with governance innovation has a better chance than technology-only or governance-only measures to create clearer, more scalable, and ultimately successful measures to combat energy poverty. Here the question arises as to what innovation is.

Scientific studies contain different interpretations of the term «innovation», which can denote both the result or process, and the result and process at the same time.: For example, the study [6] presents innovation as meaningful results based on new solutions implemented in an innovatively receptive enterprise. The thesis [7] emphasizes that it is necessary to distinguish between the innovation process and the innovation result, but the desired effects in the implementation of innovations may not be obtained, because in market conditions they are carried out under the influence of uncertainty. On the contrary, [8] summarizes that innovation, when analyzed in depth, represents both processes and results in a single whole. That is, scholars study innovation as a theoretical construct, abstracting from the interrelationships of innovation with other elements of the enterprise as a complex economic system.

In other works of scholars, innovation is most often identified with the process of «choosing new combinations» within the framework of economic development and scientific and technological progress. Thus, in [9] innovation is understood as the application of any scientific and technical solutions, both new and previously known, if such application has led to positive changes in the financial and economic stability of an economic entity. In another study [10], any combination of solutions is recognized as an innovation if it was crucial to improve the firm's performance. There is also an opinion that innovation can be different combinations of elements of the entrepreneurial ecosystem that led to the emergence of new opportunities [11]. This approach seems reasonable to us, as innovation is considered as a resource of the enterprise aimed at common goals in achieving production results.

OECD and Eurostat provide the most popular definition in their Guidelines for collecting and interpreting innovation data [12]: innovation is the process of introducing a new product or process, as well as their significant improvements, a new marketing or organizational method into business practice, in the processes of organizing jobs and establishing external relations. Here, the terminological relationship between "innovation" and "innovation" is emphasized, but the focus of innovation on the development goals of the enterprise is not emphasized. Nevertheless, the broadening of the understanding of innovation should be recognized as positive, and, developing this approach, it is possible to represent innovation as both a management tool for business, an engineering idea, and a process of accelerating the development of production.

This understanding of innovation makes it easy to integrate it into any part of the energy efficiency system. Energy efficiency, in fact, can be one of the indicators of innovative activity of the enterprise, if innovative methods and technologies are applied to its increase. This is a traditional direction in modern science with a fairly broad research base.

Energy efficiency is defined as a quantitative ratio of the volume of output products (goods, works, services, including produced energy resources) to the initial energy resources spent. Note that the definitions of most foreign studies overlap with this and additionally contain a link to environmental efficiency. For example, in the study [13], the ratio of enterprise output to energy resources used is proposed to be corrected for the change in carbon dioxide emissions, and only under this condition take the result as the desired effect. But at the same time, this approach has a weak connection with the economic efficiency of production, which is very important for enterprises of the developing economy. On the other hand, as emphasized in the paper [14], it is for developing countries that the environmental component of energy efficiency should be a priority, especially in the secondary industry, as they lag significantly behind developed countries in this indicator. However, international organizations (OECD, Eurostat, IEA) calculate energy and environmental performance indicators separately, so in this study we will follow the same approach. The critical review shows that in each case innovations applied directly to energy technologies (energy innovations) are investigated. Accordingly, the hypotheses of such studies about the positive impact of energy innovation on energy efficiency are a priori provable.

First of all, scientific research on energy efficiency is mostly focused on the study of contributing technological processes and operations. A study [15] shows a significant relationship between the diffusion of foreign technologies and energy efficiency performance in a particular country. Within the framework of the EU Erasmus+ project [16], the experience of developed European countries shows that the focus on energy efficiency allowed them to become leaders in the production and export of innovative technologies. For example, the European Environment Agency has developed a reference document [17] containing information on the best available energy efficiency technologies for the following processes: combustion, heat recovery, cogeneration, power supply, heating, ventilation, air conditioning, drying, separation, concentration and many other process operations used in more than thirty industries.

Another part of the research covers energy efficiency as a challenge for the operation of the enterprise as a whole. Economists offer recommendations for the formation of an energy management system or provide clarification of the basic concepts of energy efficiency of the enterprise through indicators: thermal efficiency, specific power consumption, energy capacity index and others. It should be noted that among the various approaches to the organization of management, different studies often consider issues devoted to the justification and selection of energy-saving solutions for business. For example, the following is suggested:

– methodology for improving energy efficiency at different levels of organization management [18];

– economically justified measures to assist industrial enterprises in selecting and applying energy efficient solutions [19];

– methodology for planning economic activities to achieve efficient energy consumption [20].

Based on our analysis of the concept of innovation presented above, all energy efficiency solutions that improve production results are innovative. Consequently, energy efficiency can be included in the overall innovation sphere of the enterprise, which will enhance the multiplicative effect if there is a direct relationship between these elements in the enterprise as an economic system.

Let us draw attention to the fact that the review of studies on energy efficiency revealed a significant gap between the theoretical foundations and practical application of the developed concepts. Modern enterprises apply the process approach described in ISO 50001 (international standard of energy management). However, this standard establishes only basic requirements for the creation, application, maintenance and improvement of the energy management system. It also does not take into account the industry specifics of different business entities.

For many researchers, the issues of studying management methods and ways of realizing the current potential for improving energy efficiency at industrial enterprises, as well as their adaptation to international standards in the energy management system and the development of integrated solutions are still relevant. The paper [21] emphasizes the equivalence of energy management and energy efficient technologies for enterprise development. Using the experience of different countries as an example, it was found that up to 10–12 % of the total energy efficiency improvement potential can be obtained when energy efficiency is included in the strategy of industrial enterprises. Another study [22] substantiates the need to disseminate international standards and successful experience in improving energy efficiency at enterprises to optimize costs, improve the quality and competitiveness of manufactured products. The paper [23] shows how energy audit of an industrial enterprise allows one to comprehensively solve the problems of energy costs of its functioning. Thus, most of the works in the field of energy management are focused on energy costs, which significantly limits the potential of its application.

In some scientific studies [24] energy efficiency is considered as one of the factors of innovative business development. The authors propose various innovative technologies for implementation in the energy sector [25] and substantiate the importance of organizational mechanisms for achieving innovative progress in the field of energy efficiency management [26]. But such works have as their subject of research innovations within the energy system itself, while the relationship between the energy efficiency of the production process and the innovation activity of the enterprise as a whole is not reflected. This scientific tendency has a reason for conditional (theoretical) division of energy innovations and other innovations at the enterprise into different non-intersecting spheres, while in a complex economic system there may be latent connections. For example, if there is a direct relationship between energy efficiency and innovation activity of an enterprise, then in management it is possible to use the impact on one sphere in order to influence the other or to combine both spheres in the management unit to obtain a multiplicative effect.

Based on our review of scientific research, we can conclude that the available methods of energy efficiency management at industrial enterprises, including the use of innovations, are focused on the solution of current problems, and innovation activity is carried out as a separate direction. However, no studies of their interrelationship have been found. Because of this "limitation" there is a gap in science in terms of studying energy efficiency and innovation activities of enterprises in their interrelation, which could generate a lot of constructive solutions at the strategic level.

3. The aim and objectives of the study

The aim of the study is to establish the absence or presence and nature of the relationship between energy efficiency and innovation performance of industrial enterprises.

To achieve this aim, the following objectives are accomplished:

– to calculate the energy efficiency indicator and indicators characterizing innovation activity for industrial enterprises;

– to assess the impact of indicators characterizing the innovation activity of industrial enterprises on the indicator of their energy efficiency;

– to assess the impact of the energy efficiency indicator on the indicators of innovation activity of the economic entities under study.

4. Materials and methods of research

The object of this study is energy efficiency and innovation activity of industrial enterprises in their interrelation. The study is conducted on the example of the Republic of Kazakhstan – a country with a developing economy of market type.

The study considered the hypothesis that there is a mutual influence of energy efficiency processes and innovation activity in industry by the nature of a direct relationship. It is assumed that the energy efficiency indicator has an impact on such indicators of innovation activity as the share of intangible assets and the share of research and development results in the total structure of assets of an economic entity, and that these indicators of innovation activity affect the energy efficiency indicator.

To substantiate this assumption, experimental calculations were carried out on the example of operating Kazakhstani enterprises. The indicators were calculated on the basis of official reports of enterprises on financial and economic activity. In addition, the documents of enterprises on strategic and innovative development were studied.

The first group is represented by the energy efficiency indicator calculated on the basis of the IEA methodology [27]. For the second group (the share of intangible assets and the share of research and development results in the total structure of assets of an economic entity) the classical approach to the calculation of indicators characterizing innovation activity was used [28].

The method of correlation and regression analysis was applied to test the hypothesis. The least squares method was used to estimate the parameters of the regression equation. Correlation analysis was performed using "Statistica 10" software. The absence of heteroscedasticity was checked using the Spearman test.

5. Results of the study of mutual influence of energy efficiency and innovation activity in the industrial sector of the economy

5. 1. Calculation of energy efficiency indicator and indicators characterizing innovation activity for industrial enterprises

For the sample of industrial enterprises the criterion used was the first place within their industry in the list of the largest taxpayers for 2022. This provided:

– significance of the sample for the industrial sector in line with the general population;

– significance of energy efficiency for enterprises using more energy;

– availability of financial potential to ensure innovative development.

To calculate the energy efficiency indicator, the ratio of the received revenue of the enterprise to the total volume of energy consumption was used. The formula takes the following form:

$$E=\frac{Q}{W}, \quad (1)$$

where:

– E – energy efficiency indicator;

– Q – company revenue;

– W – total consumption of electricity, heat and fuel.

For validity purposes, energy was converted to primary fuel used in generation. To adjust the energy efficiency indicator of a particular enterprise, recalculation was made using the formula: ratio of the economic entity's indicator to the average value for all analyzed enterprises (in this study, this value is equal to 100 %). The formulas used here are:

$$E_k=\frac{E_n}{E_m}, \text{ or } E_k=\frac{E_n}{100\,\%}, \quad (2)$$

where:

– E_k – adjusted energy efficiency indicator;

– E_n – energy efficiency indicator of the enterprise n;

– E_m – mean value (in this study takes the value of 100 %).

It follows that if the value of the indicator is 2 times higher than the average, a score of 200 % is set, and if it is 2 times lower than the average, a score of 50 % is set.

The dynamics of energy efficiency is defined as the change in output to the change in energy consumption over the study period. The formula is as follows:

$$D_e=\frac{\Delta V}{\Delta W}, \quad (3)$$

where:

– D_e – dynamics of energy efficiency;

– ΔV – change in output for the year;

– ΔW – change in consumption per year.

The second group of indicators relates to the innovative activity of enterprises. We used a classical approach to the calculation of indicators characterizing innovation activity: the share of intangible assets and the share of research and development results in the total structure of assets of an economic entity [29].

The share of intangible assets (K_a) reflects expenses on the formation of intellectual property objects (licenses, patents, trademarks, etc.) if documented. The following formula is used for calculation:

$$K_a = \frac{S_a}{P_a}, \quad (4)$$

where:

– S_a – the value of intangible assets at the end of the period in the total structure of assets;

– P_a – the value of all assets of the enterprise at the end of the reporting period.

Natural resource rights were not taken into account when calculating this indicator, as they do not directly characterize innovation activity.

The share of research and development results (K_i) reflects the amount of expenditure on completed research and development with a result, but which is not protected under the provisions of current legislation. The following formula is applied here:

$$K_i = \frac{S_i}{P_a}, \quad (5)$$

where S_i – total research expenses at the end of the reporting period in the structure of the balance sheet.

Table 1 summarizes the results of calculations of energy efficiency dynamics, the share of intangible assets and research and development results in the asset structure.

Table 1

Average annual dynamics of energy efficiency (D_e), share of intangible assets (D_a) and share of research and development results (D_i) of industrial enterprises of the Republic of Kazakhstan for 2018–2022

Name of enterprise	ΔD_e (%)	ΔD_a (%)	ΔD_i (%)
Tengizchevroil	1.208	100.000	–5.659
Kazzinc	1.670	19.790	100.000
Kazchrome	–1.205	10.287	–11.063
Kazphosphate	0.691	100.000	48.381
Imstalcon	0.243	24.802	44.031
Asia Gas Pipeline	–0.494	32.159	–1.388
Altynalmas	0.640	1.747	29.091
BI Development Holding	–0.372	–2.114	–8.461
Kazakhstan Aluminium Smelter	–0.671	–17.158	–13.639
Kazakhstan Utility Systems	–0.250	100.000	–5.424
KATCO JV	0.220	13.424	34.890
RG Brands	0.045	14.895	4.352
ALTAS KZ	0.856	2.836	8.711

Source: Compiled and calculated by the author on the basis of annual reports of enterprises on financial and economic activities

As can be seen from Table 1, changes in energy efficiency at the surveyed enterprises are not significant (ranging from – 1.205 to 1.670 % per year), nevertheless, for large production facilities even such fluctuations have an impact on the output of products. In addition, more than one third of enterprises (38 %) have negative dynamics of energy efficiency, and all these enterprises have negative dynamics of R&D results. The presence or absence of relationships can be verified using correlation analysis. The obtained data acted as a baseline for assessing the mutual influence of energy efficiency and innovation activity of enterprises.

5. 2. Assessment of the influence of indicators of innovation activity of industrial enterprises on the indicator of their energy efficiency

The average annual dynamics of change in energy efficiency was chosen as the resultant attribute to solve the first task of this study, and the dynamics of change in the share of intangible assets and the dynamics of change in the share of R&D results in the total structure of assets on average per year were chosen as the factor attributes. The method of correlation field analysis was used to establish the relationship between the resultant and factor attributes.

Fig. 2, 3 show the correlation fields with a trend line constructed to solve the first task of this study for a set of points of the resultant (average annual dynamics of energy efficiency, % per year) and factor (average annual shares of intangible assets and R&D results as % of total assets) attributes.

The correlation field shows the presence of a linear relationship between the resultant and factor attributes. The result of the calculations was the formation of an empirical regression equation reflecting the general trend among the variables under study. This equation is characterized by the following form:

$$D_e = -0.46 + 0.00750 D_a + 0.0223 D_i. \quad (6)$$

After that, calculations of the indicators of closeness of relationships were made. Pairwise correlation coefficients took the following values: 0.327, 0.737 and 0.0480 respectively. Cheddock's scale was used to assess the relationship. The following results were obtained:

– the presence of an average relationship between D_e and D_a;

– the presence of a strong correlation between D_e and D_i;

– the practical absence of a connection between $\boldsymbol{D_a}$ and D_i.

Using Student's criterion, the relationship between D_e and D_i is defined as significant, and the obtained coefficient is statistically significant. All other coefficients are not statistically significant.

Further, we calculated the multiple correlation coefficient R=0.797 and the coefficient of determination, which took the value of R^2=0.635. According to Fisher's criterion, this coefficient of determination can be attributed to statistically significant.

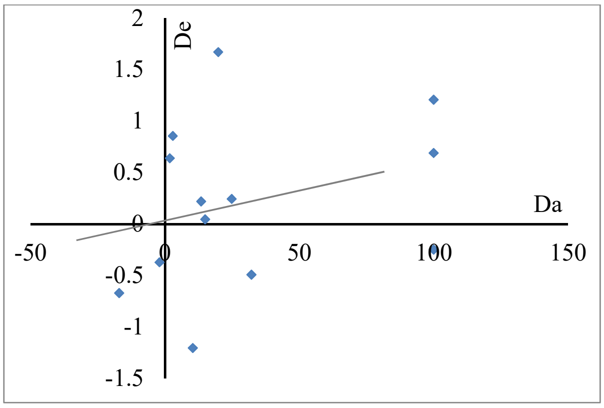

Fig. 2. Trend line for the dynamics of the share of intangible assets depending on the dynamics of energy efficiency
Source: Compiled by the author based on the results of correlation analysis

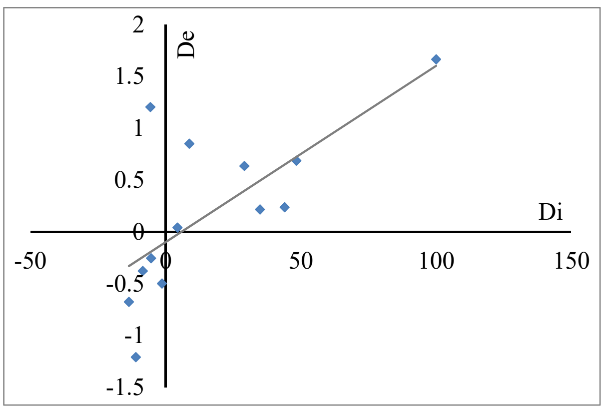

Fig. 3. Trend line for the dynamics of the share of R&D results depending on the dynamics of energy efficiency
Source: Compiled by the author based on the results of correlation analysis

5. 3. Assessment of the influence of energy efficiency indicator on the indicators of innovation activity of industrial enterprises

To solve the second problem, the average annual dynamics of the share of intangible assets and the share of R&D results (in % of total assets) were used as the resultant attributes, and the average annual dynamics of the change in energy efficiency (% per year) was used as the factor attribute. Contrary to expectations, with regard to the average annual dynamics of the share of intangible assets, the study of the correlation matrix allowed us to conclude that there is no significance between the paired linear correlation coefficients. Therefore, no further calculations were performed.

A positive result was obtained with regard to the average annual dynamics of the share of R&D results. Fig. 4 shows the correlation field with a trend line plotted for the outcome indicator of the dynamics of the share of R&D results.

The least squares method was also used to estimate the parameters of the regression equation. The result of calculations was a regression equation of the type:

$$D_i=23.8170D_e+13.99. \qquad (7)$$

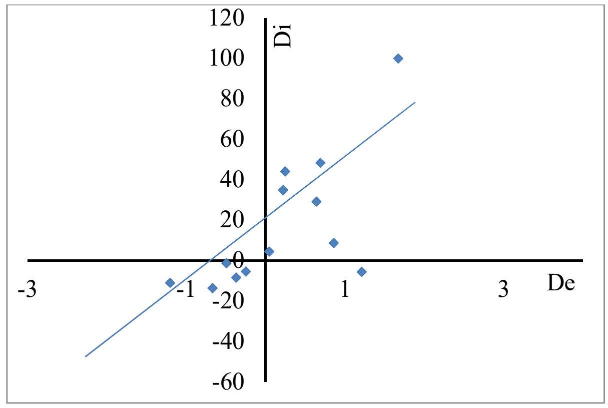

Fig. 4. Trend line for energy efficiency dynamics depending on the share of R&D results
Source: Compiled by the author based on the results of correlation analysis

Further, the index of closeness of relationships between these groups of features was calculated. Pearson correlation coefficient r_{DiDe}=0.739. According to the Cheddock scale, there is a strong and direct relationship between D_i and D_e traits.

Using Student's criterion, it was found that the observed value (t=4.63) is greater than the critical point (t=2.111), hence the correlation coefficient is categorized as significant. This confirms the existence of a linear relationship between the variables.

The next step was the calculation of the coefficient of determination R^2=0.549. This indicator characterizes the amount of variability of the resultant variable explained by the variability of the factor variable. It follows that in 54.9 % of cases the variability of D_e is the cause of variability of D_i, and in the remaining cases the changes are to be explained by other factors that are not taken into account in this model. In other words, the accuracy of the choice of the regression equation can be characterized as average. The average values of the elasticity coefficient and approximation error confirm this. However, verification with Fisher's criterion showed that the coefficient of determination is statistically significant, which indicates the statistical reliability of the selected estimate of the regression equation.

6. Discussion of the results of mutual influence of energy efficiency and innovation activities in the industrial sector of the economy

Based on the analysis, it can be stated that the studied industrial enterprises are characterized by negative (negative) trends, both in terms of energy efficiency and innovation activity (Table 1). Here it should also be noted that there are no projects combining these directions with R&D results. However, the study of intangible assets and R&D results renewal coefficients showed a high intensity of innovation activity development, for example, the average value of intangible assets renewal coefficient is 35 % and R&D results renewal coefficient is 63 %. This fact can be explained by the presence of medium-term programs with measures for innovative development with the indication of strategic objectives, allocated timeframes and available resources for this purpose. But in practice, problems arise with the formality of updating the results. The study [30] points out the importance of not only developing new ideas and technologies, but also their successful introduction to the market.

The analysis of the correlation field of the dynamics of the share of intangible assets depending on the dynamics of energy efficiency showed the presence of a linear relationship (Fig. 2). The lack of significance between the pairwise linear correlation coefficients with respect to the average annual dynamics of energy efficiency depending on the share of intangible assets may be due to the following:

1. The share of intangible assets (excluding subsoil use rights) in the structure of the balance sheet in the surveyed enterprises is on average less than 1 %, so they cannot be attributed to significant factors affecting production and economic activities and strategic directions.

2. Intangible assets as a whole practically do not affect the energy efficiency indicators of the enterprises under consideration, which is due to the underdeveloped market of intellectual property objects in the Republic of Kazakhstan and insufficient efficiency of the processes of introduction of such objects into practical activities.

The correlation field analysis revealed a linear relationship between the dynamics of the share of R&D results depending on the dynamics of energy efficiency (Fig. 3), the same relationship was established with regard to the dynamics of energy efficiency depending on the dynamics of the share of R&D (Fig. 4). This may be due to the fact that R&D results at industrial enterprises are closer to real production, as well as energy efficiency, than other forms of intangible assets (computer programs, trademarks, licenses, etc.). This also emphasizes the paramount importance of the share of R&D results in the structure of a company's intangible assets for its energy efficiency.

As it was shown in the literature review, studies of innovation activity of the enterprise and its energy efficiency, including by the method of correlation analysis, refer to innovations in the energy structure or direct energy support of the enterprise operation. The peculiarities of our results are that they refer to the innovation activity of the enterprise as a whole, not only to innovations directly related to the energy support of the enterprise. A similar study [16] also obtained results on the direct close relationship between the application of innovations in general at the enterprise and energy efficiency, but its subject was only borrowed (foreign) innovations.

Shortcomings of the study. Due to the fact that the official reporting of the studied enterprises does not present the full structure of intangible assets, the study's shortcoming is the lack of analysis of the relationship of energy efficiency with each type of intangible assets that are important for the innovation activity of the enterprise.

The study has certain limitations, as the dynamics of changes in the studied parameters is calculated for the last 5 years. Expansion of the period can give more accurate results.

The obtained results reflect the peculiarities of one country, as the sample includes only Kazakhstani enterprises. To obtain more universal results, a comparative analysis of different countries is necessary.

In addition, the results of the study may differ if the sample includes not the leading large industrial enterprises, but enterprises of high-tech industries. In the latter case, the share of intangible assets, the share of R&D in their structure, and the value of innovation indicators in real production will be different.

Unlike the results of other studies, our results are broader than the study of foreign innovation in the firm and are not limited to innovation only within the energy system. In general, we can draw a general conclusion about the presence of a direct relationship between the indicators of energy efficiency improvement and the development of innovation activity of industrial enterprises of the Republic of Kazakhstan. Based on the obtained results and conclusions these economic entities are recommended:

– to use energy efficiency improvement as a tool to achieve strategic objectives of innovative development of the enterprise;

– to integrate the processes of energy efficiency improvement and innovation activity development in the context of the management system and within the organizational structures;

– to introduce the condition «energy efficiency improvement» as a recommended condition for R&D at the enterprise;

– to increase the share of R&D in the structure of intangible assets of the balance sheet of the enterprise.

The practical significance of this study is the possibility of using the obtained approaches to improve the energy efficiency indicators of domestic enterprises in their innovative development. The results and recommendations can be implemented in the practice of economic entities of various spheres of economic management, but the greatest demand is for energy-intensive industries.

7. Conclusions

1. Dynamics of changes in both energy efficiency and innovation activity (by indicators of the share of intangible assets and R&D results) of the leading Kazakhstani enterprises in different industries over the last period showed negative trends. Renovation of intangible assets and R&D results is carried out in accordance with the existing programs, but often formally. Energy efficiency is not included in the strategic goals. Thus, there is no constructive management in these areas.

2. The dynamics of the share of intangible assets depends on the dynamics of energy efficiency (linear relationship), but there is no such dependence if the share of intangible assets is the resultant indicator. This indicates the ambiguity of relationships between these indicators, which may be due to the remoteness of the bulk of intangible assets from real production.

3. The presence of a direct strong relationship between energy efficiency and the share of R&D results at any choice of the resultant attribute indicates the priority of the share of R&D results in the structure of intangible assets for energy efficiency. This is justified by the establishment of a significant and statistically important correlation between the studied parameters. Works aimed at the search for new knowledge and its practical application for the creation of a new industrial product or technology, in one way or another affect the energy efficiency of production. In turn, changes in the energy efficiency of production affect R&D conducted at an industrial enterprise.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Financing

The study was performed without financial support.

Data availability

Data will be made available on reasonable request.

Use of artificial intelligence

The authors have used artificial intelligence technologies within acceptable limits to provide their own verified data, which is described in the research methodology section.

References

1. Schumpeter, J., Backhaus, U. (2003). The Theory of Economic Development. The European Heritage in Economics and the Social Sciences, 61–116. https://doi.org/10.1007/0-306-48082-4_3
2. Energy efficiency - targets, directive and rules. European Commission. Available at: https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficiency-targets-directive-and-rules_en
3. World Bank Group. Enerdata. Available at: https://energystats.enerdata.net/total-energy/world-energy-intensity-gdp-data.html
4. Strategy documents. European Commission. Available at: https://commission.europa.eu/strategy-documents_en
5. Varo, A., Jiglau, G., Grossmann, K., Guyet, R. (2022). Addressing energy poverty through technological and governance innovation. Energy, Sustainability and Society, 12 (1). https://doi.org/10.1186/s13705-022-00377-x
6. Akbari, M., Khodayari, M., Khaleghi, A., Danesh, M., Padash, H. (2020). Technological innovation research in the last six decades: a bibliometric analysis. European Journal of Innovation Management, 24 (5), 1806–1831. https://doi.org/10.1108/ejim-05-2020-0166
7. Ulybyshev, D., Petrenko, Y., Zhailauov, E., Kenzhebekov, N., Shevyakova, A. (2020). Evaluation of innovative susceptibility of economic subjects in the economy of Kazakhstan. The Economy: Strategy and Practice, 15 (2), 187–201. https://doi.org/10.51176/jesp/issue_2_t16
8. Syrotynska, N. M. (2015). Ekonomichne otsiniuvannia innovatsiy mashynobudivnykh pidpryiemstv. Lviv. Available at: https://lpnu.ua/sites/default/files/2020/dissertation/1393/arefsyrotynska.pdf
9. Islam, M. M., Hossain, M. M. (Eds.) (2020). Science and Technology Innovation for a Sustainable Economy. Springer International Publishing. https://doi.org/10.1007/978-3-030-47166-8
10. Abbas, J., Balsalobre-Lorente, D., Amjid, M. A., Al-Sulaiti, K., Al-Sulaiti, I., Aldereai, O. (2024). Financial innovation and digitalization promote business growth: The interplay of green technology innovation, product market competition and firm performance. Innovation and Green Development, 3 (1), 100111. https://doi.org/10.1016/j.igd.2023.100111
11. Chaudhary, S., Kaur, P., Ferraris, A., Bresciani, S., Dhir, A. (2024). Connecting entrepreneurial ecosystem and innovation. Grasping at straws or hitting a home run? Technovation, 130, 102942. https://doi.org/10.1016/j.technovation.2023.102942
12. The Measurement of Scientific and Technological Activities. Available at: https://www.oecd-ilibrary.org/science-and-technology/oslo-manual_9789264013100-en
13. Iram, R., Zhang, J., Erdogan, S., Abbas, Q., Mohsin, M. (2019). Economics of energy and environmental efficiency: evidence from OECD countries. Environmental Science and Pollution Research, 27 (4), 3858–3870. https://doi.org/10.1007/s11356-019-07020-x
14. Muhammad, S., Pan, Y., Agha, M. H., Umar, M., Chen, S. (2022). Industrial structure, energy intensity and environmental efficiency across developed and developing economies: The intermediary role of primary, secondary and tertiary industry. Energy, 247, 123576. https://doi.org/10.1016/j.energy.2022.123576
15. Sun, H., Edziah, B. K., Kporsu, A. K., Sarkodie, S. A., Taghizadeh-Hesary, F. (2021). Energy efficiency: The role of technological innovation and knowledge spillover. Technological Forecasting and Social Change, 167, 120659. https://doi.org/10.1016/j.techfore.2021.120659
16. Chichulina, K. (Eds.) (2020). Economics energy efficiency: problems of nowadays and of the future. RS Global S. z O.O. https://doi.org/10.31435/rsglobal/018
17. BAT reference documents. Available at: https://eippcb.jrc.ec.europa.eu/reference
18. Salonitis, K. (Ed.) (2020). Energy Efficiency of Manufacturing Processes and Systems. MDPI. https://doi.org/10.3390/books978-3-03936-510-4
19. Aimagambetov, E. B., Gelmanova, Z. S., Ossik, Yu. I. (2015). Energy management. Karaganda: KarSU, 140. Available at: http://elib.kstu.kz/lib/document/IBIS/F5FC1AD2-4D14-4A16-87C6-76D08037F49B/
20. Bytsiura, L. O. (2021). Formuvannia stratehii enerhoefektyvnosti na pidpryiemstvi. Ternopil', 200. Available at: http://dspace.wunu.edu.ua/bitstream/316497/41779/1/aref-butscyra-na-sait.pdf

21. Sadykov, N. O. (2021). Instrumenty povysheniya energoeffektivnosti promyshlennyh predpriyatiy. Internauka, 16 (2), 63–65.
22. Balandin, V. S., Davydov, I. N. (2023). Energosberegayushchie tehnologii v razreze promyshlennogo predpriyatiya. Trudy Mezhdunarodnoy nauchno-prakticheskoy konferentsii «XV Saginovskie chteniya. Integratsiya obrazovaniya, nauki i proizvodstva». Karaganda: KarTU, 445–446. Available at: http://elib.kstu.kz/lib/document/TEMAT/C9B7E8F5-9AF2-45FC-8E5C-344189B4C82D/
23. Abdrahmanov, E., Smirnov, D. (2022). Comprehensive energy saving on food industry enterprises. KazATC Bulletin, 123 (4), 416–425. https://doi.org/10.52167/1609-1817-2022-123-4-416-425
24. Karduri, R. K. R., Ananth, C. (2023). Energy Efficiency in Industrial Sectors: Future Directions. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.4637816
25. Tarakbayeva, R. Ye. (2020). Technological innovations aimed at nature conservation. Bulletin of «Turan» University, 1, 214–218. Available at: https://vestnik.turan-edu.kz/jour/article/view/1099/987
26. Perebyynis, V., Rogoza, M., Bezruk, D., Vitriuk, N. (2023). Economic and Managerial Aspects of Energy Efficiency of Economic Entities in Territorial Communities. Herald of the Economic Sciences of Ukraine, 1 (44), 3–12. https://doi.org/10.37405/1729-7206.2023.1(44).3-12
27. Energy Efficiency Indicators: Fundamentals on Statistics. IEA. Available at: https://www.iea.org/reports/energy-efficiency-indicators-fundamentals-on-statistics
28. Taques, F. H., López, M. G., Basso, L. F., Areal, N. (2021). Indicators used to measure service innovation and manufacturing innovation. Journal of Innovation & Knowledge, 6 (1), 11–26. https://doi.org/10.1016/j.jik.2019.12.001
29. Ibyzhanova, A., Rustenova, E., Sultanova, Z., Talapbayeva, G., Yerniyazova, Z. (2023). Evaluation of the effectiveness of government support for technology entrepreneurship. Eastern-European Journal of Enterprise Technologies, 5 (13 (125)), 36–46. https://doi.org/10.15587/1729-4061.2023.286390