BILINGUAL PUBLISHING GROUP

Journal of Environmental & Earth Sciences

https://journals.bilpubgroup.com/index.php/jees

ARTICLE

The Impact of Energy-Efficient Technologies on the Development of the Agricultural Industry

Kateryna Andriushchenko [1] **,** ***Anastasiia Liezina*** [1*] **,** ***Alla Slavkova*** [2] **,** ***Pavlo Logvinov*** [3] **,** ***Vitalii Lavruk*** [4] **,** ***Serhii Petrukha*** [5] **,** ***Andrii Storozhenko*** [6]

[1] *Department of Business Economics and Entrepreneurship, Kyiv National Economic University Named after Vadym Hetman, 03057 Kyiv, Ukraine*

[2] *Department of Finance Named after V. Fedosov, Kyiv National Economic University Named after Vadym Hetman, 03057 Kyiv, Ukraine*

[3] *Head of the Municipal Economic Development Department, Uzhhorod Municipality, 88000 Uzhhorod, Zakarpattia Oblast, Ukraine*

[4] *Department of Finance, Banking, Insurance and Electronic Payment Systems, Higher Educational Institution «Podillia State University», 32316 Kamianets-Podilskyi, Ukraine*

[5] *Department of Management in Construction, Kyiv National University of Construction and Architecture, 03037 Kyiv, Ukraine*

[6] *Department of Economics, Interregional Academy of Personnel Management, 03039 Kyiv, Ukraine*

ABSTRACT

The increase in the population as a whole gradually requires solving the issues of continuous development of the agro-industrial complex in all directions and components. This development is accompanied by an increase in energy consumption, in the total balance of which electricity occupies a significant share. *The purpose of this study is to develop a mathematical model of the use of infrared means for heating agro-industrial premises, which affects the formation of energy-saving and energy-saving processes of enterprises.* The agrarian potential of Ukraine was analyzed and compared

*CORRESPONDING AUTHOR:
Anastasiia Liezina, Department of Business Economics and Entrepreneurship, Kyiv National Economic University Named after Vadym Hetman, 03057 Kyiv, Ukraine; Email: lezya86@gmail.com

ARTICLE INFO
Received: 30 October 2024 | Revised: 16 November 2024 | Accepted: 19 November 2024 | Published Online: 25 December 2024
DOI: https://doi.org/10.30564/jees.v7i1.7635

CITATION
Kateryna Andriushchenko, Anastasiia Liezina, Alla Slavkova, et al., 2024. The Impact of Energy-Efficient Technologies on the Development of the Agricultural Industry. Journal of Environmental & Earth Sciences. 7(1): 423–437. DOI: https://doi.org/10.30564/jees.v7i1.7635

with other countries of the world for awareness, analysis and relevant conclusions regarding energy consumption and frugality. *This helped, based on calculations and foreign experience, to prove the effectiveness of the proposed mathematical model.* And its empiric results of application in the form of the use of a copper plate allowed to prove efficiency due to the reduction of electricity consumption in the conditions of maintaining the temperature regime of industrial-type premises not higher than 22–26 °C when the equipment is operating at an output power of 40 W. *The results of the research are the development of the existing theoretical foundations of ensuring the effective use of energy resources in agricultural organizations and can be used by economic entities and regional authorities for the purpose of making informed decisions in the field of energy-saving policy development in the agricultural sector.*

Keywords: Agricultural Industry; Electric Power Industry; Development; Latest Technologies; Innovations

1. Introduction

Sustainable development in the world scientific community is considered as a system of criteria, the observance of which allows to preserve enough means for the normal life of future generations. Methodologically, the innovative context of sustainability is considered in two main directions — the institutionalization of economic relations and the overcoming of deep social and territorial differentiation of civilizational development [1].

Such directions and basic principles of preventing energy poverty are primarily defined today in the Directives of the European Union [2] and the presented official notification of the European Commission of the Fourth Energy Package "Clean Energy for Europeans" [3]. The regulations provide for focusing attention on measures to improve the energy efficiency of buildings for vulnerable consumers energy resources while encouraging them to actively participate in reducing costs, based on clear, timely and reliable information on energy consumption and monitoring of savings.

In this context, it is worth noting the leading EU countries, which, in our opinion, are most successfully implementing the energy efficiency strategy. According to the existing views, concrete work is being carried out in Germany regarding energy saving and increasing the energy efficiency of systems, machines, devices and mechanisms. During the period 2000–2003, the German authorities annually contributed at least 200 million to the development of renewable energy and energy saving euro. During 2003–2005, the financing of such projects was increased to 360 million euros. And since 2006, the growth of annual capital contributions to renewable energy has become even more significant and amounted to about 1 billion euros. The authorities actively attract private capital to participate in new projects, using for this such means as the organization and holding of competitions for the implementation of energy-saving credits, the provision of benefits in taxation and obtaining credits. For example, the Polish authorities have harmonized national legislation with regulatory and legal documents of the EU.

Thus, as a result of the experience of European countries, it is worth noting that there are practically no discrepancies between national and local legal acts, and comparing the legislative framework of Ukraine, the same conclusion can also be drawn. The institutional and organizational support for energy saving policy is being successfully formed. Effective and purposeful work of state and local governments has been established in the country authorities, financial and commercial structures, business entities regarding the implementation of energy saving measures in the residential sector, effective use of local resources and electricity, implementation of solar energy, biogas production, waste disposal, obtaining thermal and electrical energy from the burning of straw and other plant waste. The energy conservation policy of other countries is also of interest. In particular, the Netherlands is one of the leaders in the development of wind energy and energy using biofuels. Significant achievements have been made in the creation of cogeneration systems and heat pumps. Great Britain is adjusting its energy policy, directing it on the one hand to economical use of energy, and on the other hand to increasing the efficiency of energy supply. In order to improve the country's energy supply, in mid-2008 it was decided to unfreeze its nuclear energy development program. The first step in solving this issue was the contract with the French company Electricite de France SA to acquire British Energy, which produces up to 30% of all electricity in England and Scotland. With the completion of the agreement, the French company will start building new nuclear power plants in Great Britain.

One of the most important conditions for the socio-economic stability of society, ensuring the economic and food security of the state is the sustainable development of agriculture, which involves the balanced achievement of economic, social and environmental goals. In accordance with the direction of the state to join the European Union, a number of legislative acts and regulations have been adopted, which have a common European integration direction. In view of the above analysis of the development of energy efficiency in the EU at the legislative level and the analysis of the practice of application in our country, there is a Law of Ukraine "On the Strategy of Sustainable Development of Ukraine for the period until 2030" [4], which clearly prescribes plans and tasks for improving the areas of state activity, in particular in the agricultural sector. At the moment, Ukraine has a developed food complex, which is able not only to fully provide the country's population with food products, but also to form an active position of the country on the international markets of a number of key agro-food products [5]. Thanks to traditionally strong food exports, Ukraine is one of the guarantors of food security in the world.

Based on the data of the National Bank of Ukraine, before the full-scale war, Ukraine was one of the five largest grain exporters in the world, exporting 3/4 of what it produced, domestic grain consumption was only 20–25%. Ukraine supplied 10% of world exports of wheat, more than 14% of corn and more than 47% of sunflower oil [6]. Currently, thanks to the help of partners, Ukraine remains a key supplier on the world markets of grain and sunflower oil, with a share of more than 10% of international trade. In 2023, 16.1 million tons of wheat were exported to 65 countries, 26.2 million tons of corn to 80 countries, and 5.7 million tons of sunflower oil to 130 countries [7].

Against the backdrop of all the positive aspects and indicators of agricultural activity in Ukraine, the issue of electrification of this industry remains open. It should be noted that the events of recent years have only aggravated the negative impact of the war and brought enormous damage to the sphere of stable power supply.

At the moment, energy efficiency in agriculture is considered as a set of organizational, economic and managerial measures aimed at creating a production system that ensures increased returns in the form of final products and the best use of the biological potential of plants and animals [8, 9]. There are general problems in the field of energy conservation and energy efficiency improvement, namely - significant wear and tear of fixed assets, high equipment breakdown due to exceeding its service life and insufficient technological discipline; significant losses in energy production and consumption, high consumption of primary fuel resources; inconsistency of production equipment with the modern scientific and technical level, etc. [10]. There are also universal ways to reduce energy consumption. These include: multi-tariff accounting system; compliance with modern building codes and requirements for thermal insulation of buildings, design of ventilation and lighting; temperature control in buildings, heating and water heating systems; application of other energy-efficient technologies of engineering systems; use of energy-saving lamps, etc. On the other hand, there are standard energy-efficient measures developed specifically for agriculture. They are provided for by the latest legislative norms and Ukraine's desire to join the European Union; within the framework of the signed agreements, one of the main stated objectives of the state program is to reduce emissions of greenhouse gases into the atmosphere - CO_s, methane, nitrous oxide, etc. [11]. According to this program, the economic potential from reducing greenhouse gas emissions by 2030 should be $3.1 million. And the effect of reducing greenhouse gas emissions through energy production based on the use of renewable energy sources (RES) according to calculations of the same program by 2030. should amount to 18.5 million tons of CO_2 equivalent.

Accordingly, the development of rural electrification makes agricultural production more susceptible to the achievements of scientific and technological progress [12, 13]. One of the key factors in the cost of the resulting agricultural product is its energy intensity. Namely, the amount of energy expended to produce a unit of output. According to this indicator, our manufacturers have a significant lag behind their Western colleagues. Undoubtedly, geographical location and climatic conditions have a significant influence, but there is also no point in denying shortcomings in the technologies used, technical devices and control systems [14].

Agriculture, in order to increase the competitiveness of its products, inevitably faces the need for modernization. The key goal is to increase productivity and reduce energy consumption[15]. Replacing outdated lamps with modern lamps with LED lamps allows not only to significantly save energy, but also to improve the quality of the lighting system. When using aero zone technologies in beekeeping, the use of toxic drugs for the treatment of bee diseases is reduced, and the productivity of bee colonies is increased. When growing plants using aeroponics, not only does the yield increase, but also the ability to harvest several times a year. With this method, there is no contact of plants with microorganisms that are in the ground.

Factors for successfully running a modern agribusiness include:

- energy efficiency of production processes;
- application of environmentally friendly production technologies;
- modern management system.

The application of innovative approaches to energy conservation in agriculture should solve the problem of not only reducing direct (variable) and total energy costs, but also improving the overall level of profitability and profitability of enterprises. In the future, the funds saved through rational use of energy should be directed to further energy-saving measures (i.e., work on the principle of reinvestment) in the direction of increasing production capacity[16, 17].

One of the areas of energy saving in the agricultural sector is the expansion of the use of non-traditional renewable sources, including solar and wind energy, as well as the use of biogas technologies. In addition, in today's conditions, management technologies for increasing energy efficiency, consisting of the development, implementation and certification of energy management systems, are becoming increasingly widespread. Thus, the state of energy networks, which ensures constant, stable development of agriculture, requires modernization and improvement. These issues are quite relevant and in demand, which attracts our attention and will be discussed in this work.

The issue of achieving energy independence is extremely urgent. Agriculture from ancient times was and will continue to be the starting point for the reproduction of social and economic systems[18]. The scientific discussion regarding the issues in the given context within the agro-economic discussion has been going on for a long time[19].

Agro-industrial discussions and the importance of energy independence in the agro-industrial complex on the basis of sustainable development are present in the works of various foreign authors[20]. This is how the work that caught our attention[21] pays enough attention to the economic effect of conducting agricultural activities in India and summarizes scientific findings with conclusions about financial results (gaining profitability and reducing costs) and economic results (including opportunity costs and saving resources). In this way, the analysis of the impact of the use of alternative sources of nutrition for watering plants on obtaining a positive economic effect in agriculture is observed. The work[22, 23] covers the debatable issues of agrobiotechnologies and management in this direction based on the results of the analysis of agro-industry in the countries of Latin America, the USA and Europe. The work presents in detail the influence of intellectual property on the formation of agrobiotechnologies and the consequences of its application. The author dedicates his work to revealing the boundaries of the concept of intellectual property and claims that it is more than a tool of technical and legal management. In this context, it becomes clear that the latest developments in the direction of energy saving can also be attributed to intellectual property, and then there is an unresolved issue of devoting greater importance to the energy independence of the agricultural sector than just a tool for the improvement and sustainable development of this industry.

Using the example of other countries, scientists evaluate the impact of using alternative power sources on improving the situation of agro-industrial complexes. For example,[24] believes that the integrated model of renewable energy management is a promising direction for Turkey. His concept is based on the idea that "... practically there is only one problem - energy..., ... human food products are also types of energy resources that, through a specific internal combustion engine (stomach), ensure his vital activity...", thereby putting the problem of energy supply in the first place. The author used a multi-objective linear programming model to use renewable energy sources for geographic regions during the planning period. This method is interesting as an example of experience and possible application practice, but needs to be expanded in a wider context of application for the agricultural sector as a whole.

And in the study[25] there is a position that: "the role of the agricultural sector is undoubtedly decisive in the combination of elements of energy and food security of the state", therefore "...a balanced, balanced and economical strategy for the development of bioenergy is needed as one of the main components of the system development of the agricultural sector".

In this direction, the opinions of the authors [26, 27] who study the issue of energy independence in rural areas are interesting. The authors are convinced that to ensure energy independence, it is necessary to create conditions for the development of energy-efficient villages, the formation of new types of energy value-added chains and market structures, that is, they consider the organizational and institutional component of achieving energy independence. We are struck by this development, but we are aimed at considering the broader context of the formation and impact of energy efficiency on the development of the agricultural sector.

Thus, from the analysis of research on the issue of energy independence, it can be seen that almost all researchers are supporters of the "renewable" model with the mandatory use of the biological field of energy resource accumulation, which corresponds to the principles of sustainable development, at the same time, further research is needed to determine the role of the agrarian sector of the economy in ensuring not only the industry's own energy independence, but also the country's on the basis of sustainable development.

2. Materials and Methods

Energy consumption plays a key role in the agricultural sector. Many factors depend on constant, stable and reliable food. According to the latest observations and studies, the most important costs are the consumption of electricity for heating the premises and maintaining them at the required temperature. The analysis of the review of literary sources and the latest developments showed an array of proposals and scientific developments, but all of them differ in a highly specialized direction, where attention is paid only to certain types of agro-industrial complex. While there is no generalized method, but if it is used, it would be possible to optimize the means of catching heating in full.

Analytical assessment of the room temperature outside local heated zones when mathematically modeling the heat exchange of the room with the environment, it is rational to use a complex parameter - room temperature t_p - instead of air temperature t_a and radiation temperature of the internal surfaces of enclosing structures τ_R. This allows temperature control to be carried out virtually in the room $t_{s.p.}$. The value of tp can thus be defined as:

$$t_p = At_a + B_R, \tag{1}$$

where A—thermal coefficients characterizing the degree of thermal impact in the middle of the room

B—thermal coefficients characterizing the degree of thermal impact from the outside on the room.

It is worth noting that:

$$A = 1 - B, \tag{2}$$

The value B is taken for heating rooms with animals - 0.42, for rooms without animals - 0.3.

More precisely, the values of A and B can be obtained from the thermal characteristics of the premises as:

$$A = \alpha_c/(\alpha_r + \alpha_c) \tag{3}$$

$$B = \alpha_r/(\alpha_r + \alpha_c) \tag{4}$$

where α_c—is the convective heat transfer coefficient

α_r—is the radiative heat transfer coefficient.

Let's determine t_p for a room with specific t_a and τ_R. Consider two cases.

1. A room with idealized climatic conditions and heating, where $t_a^c = t_R^c = \ t_p = t_{s.p.}$ At the same time:

$$Q_s^c = Q_r^c + Q_c^c, \tag{5}$$

$$Q_r^c = \alpha_r^c \left(\tau_{sur}^c - t_p\right) \varphi_R F_\Sigma, \tag{6}$$

$$Q_c^c = \alpha_c^c \left(\tau_{sur}^c - t_p\right) F_\Sigma, \tag{7}$$

where Q_s^c—is the total heat loss of the room, W,

Q_r^c—radiant heat loss of the room, W,

Q_c^c—convective losses of the room, W,

α_r^c—heat transfer coefficients by radiation, W/m^2 °C,

α_c^c—heat transfer coefficients by convection, W/^{2} °C,

τ_{sur}^c—room surface temperature °C,

φ_R—irradiance coefficient;

F_Σ—area, m^2.

2. A room with an updated approach to heating, where t_a and τ_R, at the same time $t_a \neq \tau_R$, then:

$$Q_s^p = Q_r^p + Q_c^p, \tag{8}$$

$$Q_r^p = \alpha_r^p \left(\tau_{sur}^p - t_R\right) \varphi_R F_\Sigma, \tag{9}$$

$$Q_c^p = \alpha_c^p \left(\tau_{sur}^p - t_a\right) F_\Sigma, \tag{10}$$

where Q_s^p—general updated data on heat loss of the room, W,

Q_r^p—updated radiant heat loss of the room, W,

Q_c^p—updated convective losses of the room, W,

α_r^p—updated heat transfer coefficients by radiation, W/m^2 °C,

α_c^p—updated heat transfer coefficients by convection, W/m^2 °C,

τ_{sur}^p—room surface temperature °C,

φ_R—irradiance coefficient;

F_Σ—area, m^2.

The state of the room is the same and corresponds to the same $t_{s.p.}$ value (i.e., $Q_s^c = Q_S^p = \tau_{sur}^c = \tau_{sur}^p$) and, therefore, the temperature conditions are equivalent. Then we get:

$$t_p = \alpha_c^p t_0 \left(\alpha_r^c + \alpha_c^c\right) + \alpha_r^p \tau_R / \left(\alpha_r^c + \alpha_c^c\right) + \left[1 - \left(\alpha_r^p + \alpha_c^p\right) / \left(\alpha_r^c + \alpha_c^c\right)\right] \tau_{sur} \quad (11)$$

The assumption φ_R= 1 is accepted. In this case, the assumption is justified.

$$\alpha_c^c = \alpha_c^p = \alpha_c, \quad (12)$$

Then:

$$t_p = \alpha_c t_a / \left(\alpha_r + \alpha_c\right) + \alpha_r \tau_R / \left(\alpha_r + \alpha_c\right), \quad (13)$$

Assessing the temperature in rooms for local heating usually uses equations like (1) in the form:

$$t_{s.p.} = At_a + B\tau_R + CE, \quad (14)$$

where C—the heating coefficient, °Cm^2/W;

E—heat flux from the infrared emitter, W/m^2.

In this case, it is customary to use the relation:

$$C = kk_1, \quad (15)$$

where $k \approx 1$ is the experimental coefficient;

k_1 —calibration coefficient.

The use of the coefficient C = 0.04 m^2 °C/W is not sufficiently justified (for some types of premises where more intense heating is required, such studies are currently practically absent).

In this regard, C requires clarification. For this purpose, it is of interest to analytically determine k_1 as a function of several variables and compare the calculation results with experimental data.

3. Results

As a result, to measure the value of E, a flat thermoelement design was used, which was a copper-constantan thermocouple with a diameter of 0.5 mm, soldered from below onto blackened copper foil (a 50 × 50 mm square, 0.5 mm thick). When measuring E, the thermoelement was located in the air under a 250 W infrared lamp at a level corresponding to the position of the irradiated surface of the animal's body. The measurements were carried out at room temperature under conditions of natural air convection.

To determine k_1, consider the heat balance of the specified plate (thermoelement) under uniform infrared heating. The components of the thermal balance of the plate are shown in **Figure 1.**

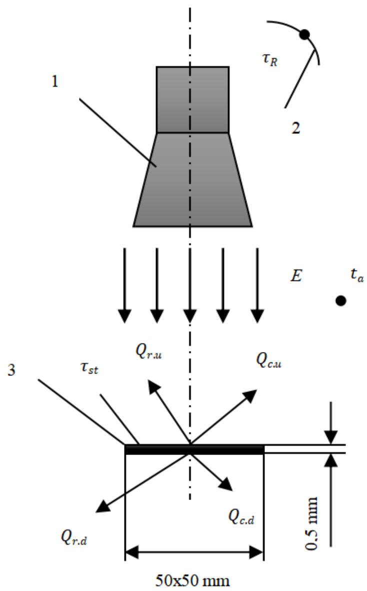

Figure 1. Calculation diagram of the heat balance of a heated object.

Where 1 is the source of infrared radiation: 2 is the internal surface of the building envelope (fragment); 3-heated plate.

Let us assume that the thermoelement, which has the form of a flat metal plate with an area F = 0.025 m^2 with a negligibly small thickness, has a steady-state temperature τ_{st}, °C, which is the same throughout its entire volume. We neglect heat transfer from the ends of the plate. The plate is irradiated from one (top) side, and heat is removed into the room from both sides (that is, the heat-transferring surface is twice as large as the heat-receiving surface). Taking this into account, the plate heat balance equation has the form:

$$aEF = Q_{r.u.} + Q_{c.u.} + Q_{r.d.} + Q_{c.d.} \quad (16)$$

where a = 1—the coefficient of perception of infrared radiation by the blackened plate;

$Q_{r.u.}$—radiant heat transfer from the upper surface of the plate under consideration, W

$Q_{c.u.}$—convective heat transfer from the upper surface of the plate under consideration, W

$Q_{r.d.}$—radiant heat transfer from the lower surface of the plate under consideration, W

$Q_{c.d.}$—convective heat transfer from the lower surface of the plate under consideration, W

$$Q_{r.d.} = Q_{r.u.} = \varepsilon_{p1} C_0 \left[0.81 + 0.005\left(\tau_{st} + \tau_R\right)\right] \times \left(\tau_{st} - \tau_R\right) F, \tag{17}$$

$$Q_{c.u.} = 2.17\left(\tau_{st} - t_a + 60V_a^2/l_{pl}\right)^{1/3} \left(\tau_{st} - t_a\right) F, \tag{18}$$

$$Q_{c.d} = 1.6\left(\tau_{st} - t_a + 60V_a^2/l_{pl}\right)^{1/3} \left(\tau_{st} - t_a\right) F, \tag{19}$$

where $\varepsilon_{p1} \approx 1$—the reduced emissivity of the surface of the room and the internal surfaces of enclosing structures in the room;

l_{pl} = 0.05 m — characteristic size of the plate surface.

Let's denote

$$\Delta\tau_1 = ak_1 E, \tag{20}$$

where $\Delta\tau_1$—the plate temperature increments due to the action of infrared radiation, °C.

To simplify the calculations, we accept

$$\tau_R = t_a \tag{21}$$

Then

$$\tau_{st} - \tau_R = \tau_{st} - \tau_a = \Delta\tau_1 \tag{22}$$

When solving (8) and (13) together, taking into account (18), we have the expression:

$$k_1 = \left[2\varepsilon_{pl} C_0 \left(0.81 + 0.005\Delta\tau_1\right) + 3.33\left(\Delta\tau_1 + 60V_a^2/l_{pl}\right)^{1/3}\right]^{-1} \tag{23}$$

Figure 2 shows the obtained results of calculations according to the dependence $k_1 = f(\Delta\tau_1; V_a)$.

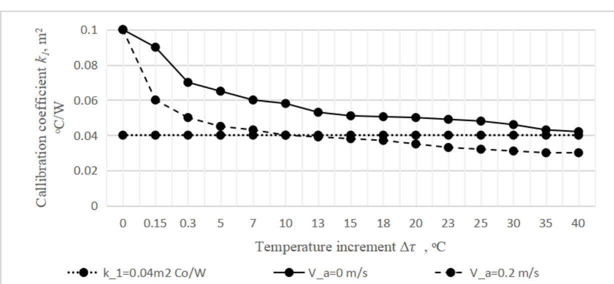

Figure 2. Dependence of the calibration coefficient k_1 on $\Delta\tau$.

As can be seen from **Figure 2**, the approximation of the experimental data k_1 direct k_1= 0.04 m^2 °C/W agrees quite well with the calculated data at V_a= 0.2 m/s and 15 °C $\Delta\tau_1$ > 8 °C. For lower values of V_a and $\Delta\tau_1$, use the value k_1= 0.04 m^2 °C/W can lead to significant errors.

The values of components (23) are determined in accordance with (8), (9) and (10). In accordance with (11), we consider 2 cases:

1. TAC = τRC = TP = TS.P.

Then

$$Q_S^c = Q_r^c + Q_C^C, \tag{24}$$

$$Q_r^c = \alpha_r^c \left(\tau_{sur}^c - t_p\right)\left(F_{sh} + F_{cr}\right)\varphi_R \tag{25}$$

$$Q_C^c = \alpha_c^c \left(\tau_{sur}^c - t_p\right)\left(F_{sh} + F_{cr}\right) \tag{26}$$

2. t_a and τ_R, at that $t_a \neq R$

$$Q_S^p = Q_r^p + Q_c^p + Q_{r.sh}^p + Q_{c.sh}^p - \Delta Q_{RAD}, \tag{27}$$

$$Q_R^p = \alpha_r^p \left(\tau_{sur}^p - \tau_R\right) F_{cr} \varphi_R \tag{28}$$

$$Q_c^p = \alpha_c^p \left(\tau_{sur}^p - t_a\right) F_{cr} \tag{29}$$

$$Q_{r.sh}^p = \alpha_{r.sh}^p \left(\tau_{sur.sh}^p - \tau_R\right) T_{sh} \varphi_R \tag{30}$$

$$Q_{c.sh}^p = \alpha_{c.sh}^p \left(\tau_{sur.sh}^p - t_a\right) F_{sh} \tag{31}$$

$$\Delta Q_{RAD} = F_{ps} \alpha_{sur} E \tag{32}$$

where Q_s^p—sensible heat generation, W;

Q_r^p—radiant heat transfer with F_{cr}, W;

Q_c^p—convective heat transfer with F_{cr}, W;

$Q_{r.sh}^p$—radiant heat transfer with F_{sh}, W;

$Q_{c.sh}^p$—convective heat transfer with F_{sh}, W;

α_r^p—coefficient of radiant heat transfer from the irradiated surface F_{cr}, W/m^2 °C;

α_c^p—coefficient of convective heat transfer from the irradiated surface F_{cr}, W/m^2 °C;

$\alpha_{r.sh}^p$—coefficient of radiant heat transfer from a non-irradiated surface F_{cr}, W/m^2 °C;

$\alpha_{c.sh}^p$—coefficient of convective heat transfer from a non-irradiated surface F_{cr}, W/m^2 °C;

τ_{sur}^p—room surface temperature for F_{cr}, °C;

$\tau_{sur.sh}^p$—room surface temperature for F_{sh}, °C;

F_{sh}—area of the room perceived by infrared radiation from, in this case, a local heater;

α_{sur}—the radiation absorption coefficient.

If the thermal conditions are the same, then:

$$Q_s^c = Q_s^p, \quad (33)$$

Solving (27)–(32) with respect to $t_p = t_{s.p}$, with $\varphi_R = 1$ we obtain:

$$\begin{aligned} t_{s.p.} = &\frac{(\alpha_c^p F_{cr} + \alpha_{c.sh}^p F_{sh}) t_a}{(\alpha_r^c + \alpha_c^c)(F_{cr} + F_{sh})} \\ &+ \frac{(\alpha_r^p F_{cr} + \alpha_{r.sh}^p F_{sh}) \tau_R}{(\alpha_r^c + \alpha_c^c)(F_{cr} + F_{sh})} + \frac{\alpha_{sur} F_{ps} E}{(\alpha_r^c + \alpha_c^c)(F_{cr} + F_{sh})} \\ &+ [\tau_{sur}^c - \frac{(\alpha_r^p + \alpha_c^p) F_{cr} \tau_{sur}^p}{(\alpha_r^c + \alpha_c^c)(F_{cr} + F_{sh})} \\ &- \frac{(\alpha_{r.sh}^p + \alpha_{c.sh}^p) F_{sh} \tau_{sur.sh}^p}{(\alpha_r^c + \alpha_c^c)(F_{cr} + F_{sh})}] \end{aligned} \quad (34)$$

Let us assume, by analogy with (16) and (21):

$$\alpha_r^p = \alpha_{r.sh}^p = \alpha_r^c = \alpha_r, \quad (35)$$

$$\alpha_c^p = \alpha_{c.sh}^p = \alpha_c^c = \alpha_c, \quad (36)$$

and the room is heated in space ($F_{\sum} = F_{cr} + F_{sh} = F_{ps}$), then

$$\tau_{sur.sh}^p = \tau_{sur}^p = \tau_{sur}^c, \quad (37)$$

That

$$\begin{aligned} t_{s.p.} = &\alpha_c t_o / (\alpha_r + \alpha_{c)} + \alpha_r \tau_R / (\alpha_r + \alpha_c) \\ &+ \alpha_{sur} E / (\alpha_r + \alpha_c) \end{aligned} \quad (38)$$

$$C = \alpha_{sur} (\alpha_r + \alpha_c)^{-1} \quad (39)$$

Let us denote for simplicity:

$$1/(\alpha_r + \alpha_c) = \xi \quad (40)$$

Then formula (39) will appear in the form:

$$C = \xi \alpha_{sur} \quad (41)$$

Let us approximate the thermal characteristics of the room with straight lines corresponding to its heat transfer (**Figure 3**). In (38) and (39) it is shown that:

$$\begin{aligned} tg\gamma_r = \alpha_r \\ tg\gamma_c = \alpha_c \end{aligned} \quad (42)$$

From **Figure 3** and Equation (42) it follows that:

$$tg\gamma = tg\gamma_r + tg\gamma_c = \alpha_r + \alpha_c, \quad (43)$$

Let's consider a section of straight-line Q_s (**Figure 3**). A room with a certain t_p, which can be determined according t (1) based on the known t_a and $_R$. In this case, the room accumulates a certain amount of sensible heat $Q_{s.p}$. Suppose that under these conditions it is required to create some optimal thermal conditions in the room with $t_{s.p.opt}$, which corresponds to $Q_{s.opt}$. An increase in t (from t_p to $t_{s.p.opt}$) corresponds to decrease Q_S by Q (from $Q_{s,p,}$ to $Q_{s,opt,}$):

$$\Delta t = \xi_1 \Delta Q \quad (44)$$

where ξ_1—the compliance coefficient, °C/W.

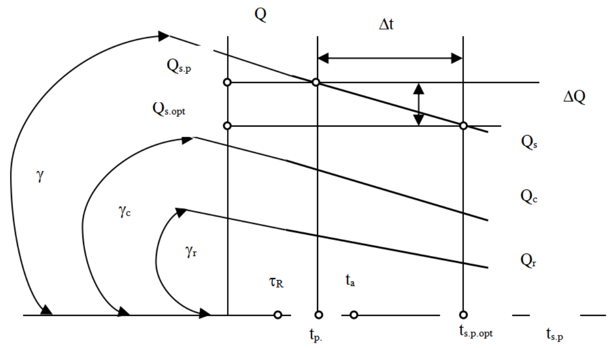

Figure 3. Calculation scheme for determining the coefficient x.

It is possible, according to (44) and **Figure 3**, note that

$$\xi_1 = \Delta t / \Delta Q = ctg\gamma \quad (45)$$

Then:

$$\xi_1 = 1/(\alpha_r + \alpha_c) \quad (46)$$

When heated by an infrared radiator, when $F_{\sum} \neq F_{ps}$, Equations (42) and (45) take the form:

$$t_{s.p.} = At_a + B\tau_R + CEF_{ps}/CEF_{ps} \quad (47)$$

$$\begin{aligned} t_{s.p.} = &\alpha_c t_a / (\alpha_r + \alpha_c) + \alpha_r \tau_R / (\alpha_r + \alpha_c) \\ &+ \xi \alpha_{sur} E F_{cr} / F_{\sum} \end{aligned} \quad (48)$$

We find the required value of E from (47) or (48) as

$$E = \frac{t_{s.p.} - At_a - B\tau_R}{(\xi a_{sur} F_{cr} / F_{\sum})} \quad (49)$$

Thus, Equations (15), (42), (48) and (49) were obtained based on solving systems of equations that describe the heat balance of rooms during heat exchange with the environment under external thermal influence, and therefore are a fairly strict expression of temperature ts. p, indoors.

Presented justifications for the dependence of the main thermal characteristics of premises as a function of its heating temperature and compliance with specified temperatures.

One of the main indicators of thermal state has been determined room – the temperature of its heat exchange surface. This indicator is necessary for use in developing a methodology for selecting the required parameters of local heaters. When it changes through external exposure to infrared radiation, it is possible to influence the state of temperature in the room.

These calculations were carried out in order to justify energy savings when heating in premises of various types and types in the agricultural sector. Available reports and cross-country comparative data were used to assess the specific energy consumption of the final agricultural product and all agricultural processes and operations, compare specific energy consumption with global benchmarks, and identify the least energy efficient sectors with the greatest potential for energy efficiency improvements. Canada, Kazakhstan, China (**Table 1**) were considered as countries with comparable conditions, as well as Germany as a developed country with low energy intensity for comparison.

When comparing the areas of land resources among countries, Ukraine occupies the penultimate place, but the amount of land does not indicate the quantity and quality of plant and animal products, which are the main ones in the agro-industrial complex of the countries. Thus, as a result of the analysis, comparative data were obtained (**Figures 4** and **5**).

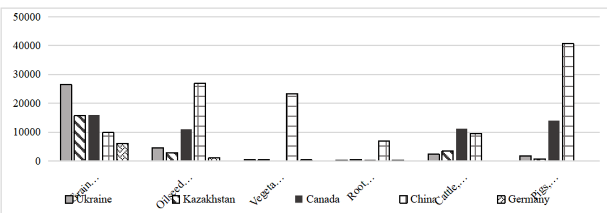

Figure 4. Harvested area of main crops and animals in Ukraine, Kazakhstan, Canada, China and Germany as of 2023.

Source: calculated by the authors based on data from [28, 29].

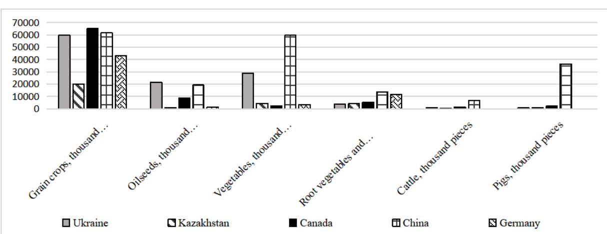

Figure 5. Volume of production of main crops and animals in Ukraine, Kazakhstan, Canada, China and Germany as of 2023.

Source: calculated by the authors based on data from [28, 29].

Thus, the results of the analysis show that Ukraine occupies one of the leading positions among the leaders in the production of agricultural products. It is the quantity and quality of the collected products that are the main factor responsible for this.

As part of our work, we are paying greater attention to energy savings and the impact of using new heating sources in agricultural premises in order to free up more and more funds that can subsequently be invested and reinvested in this sector.

In this case, based on the results of an analysis of countries with comparable production and climatic conditions, the dynamics of specific energy consumption shows that on the scale of the economy as a whole, energy intensity indicators in the country over the past 5 years are approximately twice as high as those in Germany. Energy use intensity per unit of GDP at constant purchasing power parity has slowed significantly in 2023 (−0.4% compared to −1.5%/year between 2018 and 2021). The energy intensity of the Ukrainian economy in the 2000s was higher than the energy intensity of Canada, Germany, and Kazakhstan, but subsequently the situation changed and until 2021 the indicators became more efficient. In the period from 2000 to 2021, the decrease in energy intensity of Ukraine's GDP amounted to 11%. Over the same period, the overall decrease in the energy intensity of GDP of all countries of the world was 5%, EU countries - 8%, countries, China - 9%. In this vein, it should be noted that the analysis of the energy supply of the agro-industrial complex of countries also varies according to indicators (**Figure 6**).

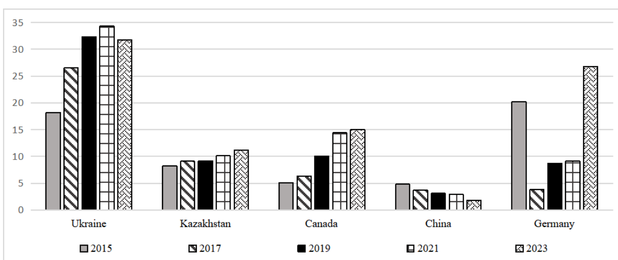

Figure 6. Energy supply of the agricultural sector in Ukraine, Kazakhstan, Canada, China and Germany as of 2023, t.s.f./100 hectares.

Thus, we can conclude that the lowest energy consumption is in China, and the above indicates that this country occupies a leading position in the production and cultivation of agricultural products. That is, based on imperial analysis,

Table 1. Land resources of Ukraine, Kazakhstan, Canada, China, Germany as of 2023.

Country	Land Area, Thousand km^2	Agricultural Land		Perennial Mowing and Pastures		Arable Land		Built-Up, Barren and Vegetated Lands	
		Thousand km^2	% of Land	Thousand Hectares	% of Land	Thousand Hectares	% of Land	Thousand Hectares	% of Land
Ukraine	604.0	424.0	70.2	14.2	2.35	55.3	9.15	31.0	5.13
Kazakhstan	2699.7	2160.4	80.0	184464	68.3	29748.4	1.1	52091.0	19.3
Canada	8965.6	626.7	6.5	19342	2.2	38687.0	4.3	490277.0	54.7
China	9424.7	5285.3	56.2	392834	41.7	119488.7	12.7	195862.0	20.9
Germany	349.4	166.4	47.6	4751	13.6	11731.0	33.6	5209.0	14.9

we believe that the proposal we presented on the use of space heating using infrared heaters can significantly affect the energy independence of the agro-industrial complex in Ukraine. This is primarily due to the confirmed evidence of the use of such methods in Asian countries. Accordingly, after all the calculations carried out, we can assume that the energy independence of the agro-industrial complex in Ukraine has every possible chance of being realized (**Figure 7**) and is reflected in the list of factors.

In a broad sense, the results obtained in this way represent a list of directions, functional characteristics and implementation mechanisms - energy independence of the agro-industrial complex determines sustainability, and sustainability - energy independence. We consider these interrelationships as certainly correlated with the motivations of the industry purpose, as well as the requirements of time, which determine the expediency of renewables as a socio-economic effect that characterizes the level of social responsibility. Thus, and in relation to the principles of substantiation of the factors of energy independence of the agro-industrial complex, sustainable development in the global perspective of knowledge of this process is a category and process that characterizes the ability of the natural-economic system to recover.

The energy independence of the agro-industrial complex is a strategic goal in ensuring the sustainable development of the national economy, because the agrarian industry is the basic one, and a significant part of the national wealth is created in it. It is all the more important that the agro-industrial complex is able to guarantee its own energy independence, in particular, autonomy at the expense of intra-industry energy potential. This potential fits organically into the system of sustainable development due to the renewable nature of the resources declared for use.

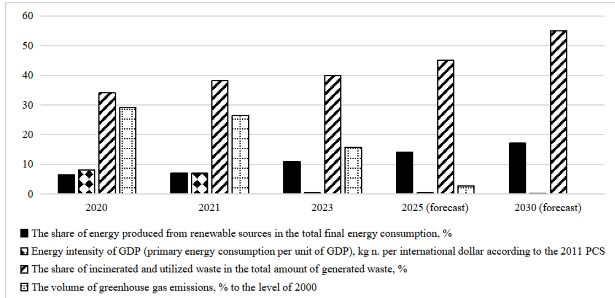

Figure 7. Results of calculations of indicators and target benchmarks for ensuring energy independence of agricultural industry in Ukraine.

4. Discussion

As a result of the calculations and analysis of the use of energy-efficient technologies for the development and sustainability of the agricultural industry in Ukraine, as well as a comparison of the basic characteristics and parameters in other countries of the world, we obtained high results of the use of an infrared heating device that reduces the total consumption of electrical energy for heating and maintaining the required temperature in premises of various types, which will lead to an improvement in the indicators of energy independence of this sector of the economy. But among scientists [30] there are opinions about the inefficient use of this particular method for the purpose of heating rooms due to the fact that it is more typical for drying. Also, [31, 32] claim that infrared radiation is currently used most often in the food industry for baking and drying products. Due to the fact that it has good properties for dehydration of food products and their heat treatment.

There is also an opinion that infrared heating should be used for recycling. In works [33, 34], the author's position is present regarding the use of high-temperature infrared furnaces for the processing of by-products of agro-industry. In these cases, the authors emphasize the use of high temperatures and monitor the positive effect in the future when using the obtained materials [35]. This position is quite widespread in the world [36], currently there is a practice of application in Asian countries. We tend to believe that these countries significantly reduce their costs in the energy dependence of agro-industrial complex enterprises due to such innovations. Therefore, it is worthwhile to single out this field of problems for future research [37]. As for our presented material, the results of developing mathematical forms and improving dependencies after the method of experiments using milking plates of infrared radiation, it is worth saying that it is a continuation of all the above-mentioned achievements and not contradicts them.

This review contained a description and raising of discussion questions regarding the method and tools of the selected research, and another component of our work - the impact on the formation of energy independence and economic levers, should be disclosed in more detail. So it is worth noting that works [33, 38] present this method as innovative and technologically new. He is also used for heating external structures in the agricultural sector, such as greenhouses, greenhouses, temporary structures for planting vegetation, etc. Paper [39] presents the analysis and results of using this method of heating vegetation, and the economic effect of its application is expressed in the return of funds for a period of 2.7 years. Which indicates a rather long time for investment recovery. In this case, it is worth thinking about the large-scale implementation of the idea of heating the premises of the agricultural industry with infrared heaters [40]. First of all, this is the high cost of this equipment. And if we take into account that this type of activity is too subject to risks (natural phenomena - drought [41], landslides, lack of precipitation, excessive precipitation, low temperatures, etc.; purchasing power - devaluation of products [42], decrease in demand, change in consumer tastes [43], large presence of substitute goods [44]; socio-political - military actions in Ukraine [45], blocking of imports, unstable fluctuations of the national currency [46], etc.), then planning activities in the next five years is quite a risky business [47]. Therefore, in our opinion, this proposal has a place to be and exist within the framework of implementation.

It is worth noting that the demand for energy-saving elements in the agricultural sector has a significant potential from an economic point of view. In works [48, 49], the results of the application of innovative methods (including infrared heaters, which we studied in this work) were investigated, based on the results of the exergy analysis method, real data were obtained regarding the effectiveness and cost-effectiveness of funds due to the reduction of electricity consumption. On the example of Turechynna, it was considered that out of 60.99% energy efficiency for RER, only 49.85% is actually used. In this way, the researchers proved the effectiveness of using alternative sources of energy generation, as well as, in parallel, the use of more economical sources of consumption. This view is also supported by studies [50] where similar calculations were made for Bangkok and Thailand. The obtained results showed a positive trend in cost savings in the amount of $123 million and a reduction in CO_2 emissions in the amount of 500,000 tons/year.

But there is another scientific point of view in this direction. There are supporters of circumstances when the use of infrared heating is the cause of overdried air [51, 52], the spread of pathogenic flora and viruses [53], as well as the formation of a flammable environment [54] is possible in the future. These scientists are supporters of the classical use of this means of heating, and their point of view is confirmed by experiments effectiveness of using infrared means. But it is worth noting that using this method only for drying and heating, energy consumption increases rapidly, and accordingly, the value expression of variable and total costs for the manufacturer increases. In this case, it is not appropriate to claim that heating with the help of infrared radiation is economically feasible in the framework of the creation of final products. And if we rely on research [55, 56], it was proved by experimental, computational and hypothetical methods that the use of infrared equipment in order to maintain a temperature regime not higher than 22–26 °C when the equipment is operating at an output power of 40 W does not lead to excess costs in the consumption of electrical energy [57], and as a result to greater consumer capacity.

That is, in view of various approaches and studies, we have facts confirming the expediency of using energy-efficient and energy-saving methods of heating premises in the agricultural sector due to the use of infrared heaters [58, 59]. And the results of the calculations prove their economic feasibility and form the basis for the formation of energy independence of this sector of the economy.

5. Conclusions

As a result of research, we have developed and formulated an approach to the effective use of heating premises for agricultural purposes using infrared heaters, identified long-term tasks of activity, principles of organization and operation, functions, methods of implementation, which were outlined and analyzed with the experience of agricultural areas of other countries. The purpose of creating this mathematical approach is to ensure the economical and rational use of energy resources used in the production of agricultural raw materials and finished products, reducing energy costs per unit of production without deteriorating the quality characteristics of the products for efficient and sustainable agricultural production.

For the effective functioning of the proposed energy saving methodology, we have formulated the main tasks that contribute to achieving the set goal:

- identification of promising areas of energy saving in agricultural organizations;
- identification of sources and reserves for saving energy resources;
- integrated use of centralized and decentralized energy supply, taking into account the use of heaters at minimum loads of electricity consumption;
- use, along with traditional, non-traditional and renewable energy sources;
- application of a system of material incentives for achieved results in energy saving;
- improving the skills of employees on energy saving issues.

The scientific novelty of the proposed development lies in the identification and substantiation of the composition and structure of energy saving in agricultural organizations based on the use of infrared sources of space heating, which allows:

- *display the multi-level nature of the construction and implementation of the energy saving process;*
- *establish the relationship and interaction of the external and internal temperature conditions of the room, determine their influence and specificity;*
- *determine the key criteria that evaluate the state of the room temperature at the internal and external levels.*

The developed mathematical model develops the existing theoretical principles to ensure the effective use of energy resources in agricultural organizations and can be used by business entities and regional governments in order to make informed decisions in the field of developing energy-saving policies in the agricultural sector, and the actual use of this method of heating agricultural premises will help reduce the amount of electrical energy consumed, which will lead to a reduction in fixed costs at the enterprise and increase their profitability as a whole.

Author Contributions

Conceptualization, K.A., A.L., A.S. (Alla Slavkova), P.L., V.L., S.P. and A.S. (Andrii Storozhenko); methodology, K.A., A.L., A.S. (Alla Slavkova), P.L., V.L., S.P. and A.S. (Andrii Storozhenko); software K.A., A.L., A.S. (Alla Slavkova), P.L., V.L., S.P. and A.S. (Andrii Storozhenko); validation, K.A., A.L., A.S. (Alla Slavkova), P.L., V.L., S.P. and A.S. (Andrii Storozhenko); formal analysis, K.A., A.L., A.S. (Alla Slavkova), P.L., V.L., S.P. and A.S. (Andrii Storozhenko); investigation, K.A., A.L., A.S. (Alla Slavkova), P.L., V.L., S.P. and A.S. (Andrii Storozhenko); resources, K.A., A.L., A.S. (Alla Slavkova), P.L., V.L., S.P. and A.S. (Andrii Storozhenko); data curation, K.A., A.L., A.S. (Alla Slavkova), P.L., V.L., S.P. and A.S. (Andrii Storozhenko); writing—original draft preparation, K.A., A.L., A.S. (Alla Slavkova), P.L., V.L., S.P. and A.S. (Andrii Storozhenko); writing—review and editing, K.A., A.L., A.S. (Alla Slavkova), P.L., V.L., S.P. and A.S. (Andrii Storozhenko); visualization, K.A., A.L., A.S. (Alla Slavkova), P.L., V.L., S.P. and A.S. (Andrii Storozhenko); supervision, K.A., A.L., A.S. (Alla Slavkova), P.L., V.L., S.P. and A.S. (Andrii Storozhenko); project administration, K.A., A.L., A.S. (Alla Slavkova), P.L., V.L., S.P. and A.S. (Andrii Storozhenko); funding acquisition, K.A., A.L., A.S. (Alla Slavkova), P.L., V.L., S.P. and A.S. (Andrii Storozhenko). All authors have read and agreed to the published version of the manuscript.

Funding

This research received no external funding.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Data Availability Statement

The results of this study, as reported in the published article, are available from the first and corresponding author upon request.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] Hegarty, J., Maubrey, R., 2020. Decision making for sustainable development. Journal of Decision Systems. 29(1), 497–510. DOI: https://doi.org/10.1080/12460125.2020.1847834
[2] Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on energy efficiency and amending Regulation (EU) 2023/955 (recast) (Text with EEA relevance) PE/15/2023/INIT. OJ L 231, 20.9.2023, pp. 1–111 (BG, ES, CS, DA, DE, ET, EL, EN, FR, GA, HR, IT, LV, LT, HU, MT, NL, PL, PT, RO, SK, SL, FI, SV). Available from: http://data.europa.eu/eli/dir/2023/1791/oj (cited 26 July 2024).
[3] Official notification of the European Commission of the Fourth Energy Package "Clean Energy for Europeans" https://energy.ec.europa.eu/topics/energy-strategy/clean-energy-all-europeans-package_en?prefLang=ro (cited 26 July 2024).
[4] Law of Ukraine On the Strategy of Sustainable Development of Ukraine until 2030 No. 9015 dated August 7, 2018. Available from: https://ips.ligazakon.net/document/JH6YF00A?an=332 (cited 26 July 2024).
[5] Siankwilimba, E., Hiddlestone-Mumford, J., Hoque, M.E., et al., 2023. Sustainablity of agriculture extension services in the face of COVID-19: A study on gender-specific market systems. Cogent Food and Agriculture. 9(2). DOI: https://doi.org/10.1080/23311932.2023.2284231
[6] FAO, 2022. Ukraine: Impact of the war on agriculture and rural livelihoods in Ukraine – Findings of a nation-wide rural household survey, December 2022. Rome.
[7] Inflation report. October 2023. National Bank of Ukraine. Available from: https://bank.gov.ua/admin_uploads/article/IR_2023-Q4.pdf?v=6 (cited 26 July 2024).
[8] Hessari, F.A., Kazemzadeh, A., Kazemzad, M. 2009. Energy, population and agriculture productivity in Iran, International Journal of Sustainable Development and World Ecology. 16(5), 308–312. DOI: https://doi.org/10.1080/13504500903217241
[9] Oukil, A., Nourani, A., Soltani, A.A., et al., 2023. Improving agricultural sustainability through farm mergers: an energy efficiency perspective. International Journal of Agricultural Sustainability. 22(1). DOI: https://doi.org/10.1080/14735903.2023.2293598
[10] Wang, Y., Zhang, W., 2022. A study about the impact of energy saving climate on college students' energy saving behavior: based on analysis using the hierarchical linear model. Journal of Environmental Planning and Management. 66(14), 2943–2961. DOI: https://doi.org/10.1080/09640568.2022.2093172
[11] Paris, B., Kanaki, V., Koutsouris, A., et al., 2024. Farmers' needs, ideas and interests on the adoption of fossil energy free technologies and strategies in the EU. International Journal of Sustainable Energy. 43(1). DOI: https://doi.org/10.1080/14786451.2024.2326454
[12] Gallego Sanchez-Torija, J., Garsia Lopez, C., Fernandez Nieto, M.A., 2023. Energy, water and economic savings by changing habits of users in twelve schools in Spain. Building Research and Information. 52(5), 596–609. DOI: https://doi.org/10.1080/09613218.2023.2277469
[13] Zinzi, M., Carnielo, E., Federeci, A., 2024. Preliminary studies of a cool roofs' energy-rating system in Italy. Advances in Building Energy Research. 8(1), 84–96. DOI: https://doi.org/10.1080/17512549.2014.890539
[14] Malla, S., Timilsina, G.R., 2018. Assessment of long-term sustainable end-use energy demand in Romania. International Journal of Sustainable Energy. 38(3), 253–275. DOI: https://doi.org/10.1080/14786451.2018.1482301
[15] Bhattacharyya, S.C., Timilsina, G.R., 2010. Modelling energy demand of developing countries: Are the specific features adequately captured? Energy Policy. 38(4), 1979–1990. DOI: https://doi.org/10.1016/j.enpol.2009.11.079
[16] Ume, C.O., Enete, A.A., Onyekuru, A.N., et al., 2020. Evaluation of agribusiness performance in Nigeria. Africa Journal of Management. 6(4), 327–349. DOI: https://doi.org/10.1080/23322373.2020.1830690
[17] Mariyono, J., Abdurrachman, H., Suswati, E., et al., 2020. Rural modernization through intensive vegetable farming agribusiness in Indonesia. Rural Society. 29(2), 116–133. DOI: https://doi.org/10.1080/

10371656.2020.1787621
[18] Young, M.M., 2011. Revisiting the impact of economic crisis on Indonesian agro-food production. Development in Practice. 21(4–5), 705–717. DOI: https://doi.org/10.1080/09614524.2011.562878
[19] Mohamed Shaffril, H.A., Hamzah, A., Md. Yassin, S., et al., 2014. The Coastal Community Perception on the Socio-Economic Impacts of Agro-Tourism Activities in Coastal Villages in Malaysia. Asia Pacific Journal of Tourist Research. 20(3), 295–313. DOI: https://doi.org/10.1080/10941665.2013.877048
[20] Andriushchenko, K., Kovtun, V., Shergina, L., et al., 2020. Agro-based clusters: a tool for effective management of regional development in the era of globalisation. TEM Journal. 9(1), 198–204. DOI: https://doi.org/10.18421/TEM91-28
[21] Nikonenko, U., Shtets, T., Kalinin, A., et al., 2022. Assessing the policy of attracting investments in the main sectors of the economy in the context of introducing aspects of industry 4.0. International Journal of Sustainable Development and Planning. 17(2), 497–505. DOI: https://doi.org/10.18280/ijsdp.170214
[22] Hernandez Vidal, N., 2018. Territorializando STS: an analysis of current discussions about agro-biotechnology governance in Latin America, Europe, and the USA. Latin American Science, Technology and Society. 1(1), 70–83. DOI: https://doi.org/10.1080/25729861.2018.1493180
[23] Pokataiev, P., Liezina, A., Andriushchenko, A., et al., 2023. The role of biotechnology in the development of the bioeconomy. Acta Innovations. 46, 18–33. DOI: https://doi.org/10.32933/ActaInnovations.46.2
[24] Semenets-Orlova, I., Shevchuk, R., Plish, B., et al., 2022. Human-centered approach in new development tendencies of value-oriented public administration: Potential of education. Economic Affairs (New Delhi). 67(5), 899–906. DOI: https://doi.org/10.46852/0424-2513.5.2022.25
[25] Tripathy, A., Acharya, P.K., 2023. Strength, life cycle analysis, embodied energy and cost-sensitivity assessment of sugarcane bagasse ash-based ternary blends of geopolymer concrete. European Journal of Environmental and Civil Engineering. 28(3), 591–610. DOI: https://doi.org/10.1080/19648189.2023.2219709
[26] Andriushchenko, K., Tkachuk, V., Lavruk, V., et al., 2021. Management of the process of formation of financial and credit infrastructure to support agricultural enterprises. International Journal of Financial Research. 12(1), 137–143. DOI: https://doi.org/10.5430/ijfr.v12n1p137
[27] Moretto, J.S., 2013. A New Energy Strategy for the United States: Energy Independence. Strategic Planning for Energy and the Environment. 33(2), 24–75. DOI: https://doi.org/10.1080/10485236.2013.10750249
[28] Cengiz Toklu, M., Candan, G., 2024. How sustainable are agricultural practices in European Union countries? A spherical fuzzy logic based evaluation. Intarnational Journal of Sustainable Development & World Ecology. 1–16. DOI: https://doi.org/10.1080/13504509.2024.2397794
[29] Loepfe, L., Lloret, F., Roman-Cuesta, R.M., 2011. Comparison of burnt area estimates derived from satellite products and national statistics in Europe. International Journal of Remote Sensing. 33(12), 3653–3671. DOI: https://doi.org/10.1080/01431161.2011.631950
[30] Andriushchenko, K., Datsii, O., Lavruk, O., et al., 2021. Development of a matrix of food industry capacity for making management decisions in the formation of sustainable development of agroecosystems. Eastern-European Journal of Enterprise Technologies. 2(13(110), 16–27. DOI: https://doi.org/10.15587/1729-4061.2021.227805
[31] Manyatsi, T.S., Al-Hilphy, A.R., Majzoobi, M., et al., 2022. Effects of infrared heating as an emerging thermal technology on physicochemical properties of foods. Critical Reviews in Food Science and Nutrition. 63(24), 6840–6859. DOI: https://doi.org/10.1080/10408398.2022.2043820
[32] Andriushchenko, K., Liezina, A., Lavruk, V., et al., 2022. Intelligent enterprise capital control based on Markov chain. Acta Innovations. 45, 75–85. DOI: https://doi.org/10.32933/ActaInnovations.45.2
[33] Riadh, M.H., Ahmad, S.A.B., Marhaban, M.H., et al., 2014. Infrared Heating in Food Drying: An Overview. Drying Technology. 33(3), 322–335. DOI: https://doi.org/10.1080/07373937.2014.951124
[34] Rubbobashta, S., Zueva, G., 2016. Drying of seeds through oscillating infrared heating. Drying Technology. 34(5), 505–515. DOI: https://doi.org/10.1080/07373937.2015.1060997
[35] Penido, E.S., de Oliveira, M.A., Sales, A.L.R., et al., 2021. Biochars produced from various agro-industrial by-products applied in Cr(VI) adsorption-reduction processes. Journal of Environmental Science and Health, Part A. 56(13), 1387–1396. DOI: https://doi.org/10.1080/10934529.2021.2000814
[36] Bonelli, P.R., Cukierman, A.L., 2015. Physicochemical Characteristics and Pyrolysis Behavior of Klason Lignins Isolated from Agro-industrial Biomass. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects. 37(14), 1534–1541. DOI: https://doi.org/10.1080/15567036.2011.627414
[37] Herbert, A., Kumar, U., 2021. Removal of Acid blue 93 dye from aqueous media using an agro-industrial waste as bioadsorbent: An OPAT and DoE Approach. International Journal of Environmental Analytical Chemistry. 103(17), 5599–5618. DOI: https://doi.org/10.1080/03067319.2021.1940987
[38] Manyatsi, T.S., Al-Hilphy, A.R., Majzoobi, M., et al.,

2022. Effects of infrared heating as an emerging thermal technology on physicochemical properties of foods. Critical Reviews in Food Science and Nutrition. 63(24), 6840–6859. DOI: https://doi.org/10.1080/10408398.2022.2043820

[39] Fasina, O.O., Tyler, R.T., Pickard, M.D., 1998. Modelling the infrarred radiative heating of agricultural crops. Drying Technology. 16(9–10), 2065–2082. DOI: https://doi.org/10.1080/07373939808917512

[40] Liezina, A., Lavruk, A., Matviienko, H., et al., 2023. Impact of econometric modeling and perspectives of economic security of the cross-industry complex. Acta Innovations. 11(47), 73–83. DOI: https://doi.org/10.32933/ActaInnovations.47.7

[41] Rabin, R.M., Burns, B.A., Collimore, C., et al., 2000. Relating remotely-sensed vegetation and soil moisture indices to surface energy fluxes in vicinity of an atmospheric dryline. Remote Sensing Reviews. 18(1), 53–82. DOI: https://doi.org/10.1080/02757250009532383

[42] Deepika, S., Sutar, P.P., 2023. Spectral selective infrared heating of food components based on optical characteristics and penetration depth: a critical review. Critical reviews in food science and nutrition. 1–23. DOI: https://doi.org/10.1080/10408398.2023.2227899

[43] Rastogi, N.K., 2012. Recent Trends and Developments in Infrared Heating in Food Processing. Critical reviews in food science and nutrition. 52(9), 737–760. DOI: https://doi.org/10.1080/10408398.2010.508138

[44] Wang, Y., Zhang, M., Mujumdar, A.S., et al., 2014. Drying and Quality Characteristics of Shredded Squid in an Infrared-Assisted Convective Dryer. Drying Technology. 32(15), 1828–1839. DOI: https://doi.org/10.1080/07373937.2014.952379

[45] Buriachenko, A., Zakhozhay, K., Liezina, A., et al., 2022. Sustainability and security of public budget of the Visegrad Group countries. Acta Innovations. 42, 71–88. DOI: https://doi.org/10.32933/ActaInnovations.42.6

[46] Mamonova, N., Wengle, S., Dankevych, V., 2023. Queen of the fields in wartime: What can Ukrainian corn tell us about the resilience of the global food system? Journal of Peasant Studies. 50(7), 2513–2538. DOI: https://doi.org/10.1080/03066150.2023.2255568

[47] Ultu, Z., Hepbasli, A., 2006. Analyzing the Energy Utilization Efficiency of Renewable Energy Resources. Part 1: Energy Analysis Method. Energy Sources Part 1: Economics, Planning and Policy. 1(14), 341–353. DOI: https://doi.org/10.1080/15567240491922238

[48] Azarenkova, G.M., Buriachenko, A., Zhyber, T., 2021. Anti-corruption efficiency in public procurement. Financial and Credit Activity Problems of Theory and Practice. 2(33), 66–73. DOI: https://doi.org/10.18371/fcaptp.v2i33.206412

[49] Ultu, Z., Hepbasli, A., 2006. Analyzing the Energy Utilization Efficiency of Renewable Energy Resources. Part 1: Energy Analysis Method. Energy Sources Part 1: Economics, Planning and Policy. 1(14), 355–366. DOI: https://doi.org/10.1080/15567240491922247

[50] Seeley, C.C., Dhakal, S., 2021. Energy and CO2 emission reduction potential from investment in energy efficiency building retrofits in Bangkok, Thailand. International Journal of Sustainable Energy. 41(2), 164–183. DOI: https://doi.org/10.1080/14786451.2021.1906244

[51] Panwar, N.L., Kothari, S., Kaushik, S.C., 2010. Experimental investigation of energy and exergy efficiency of masonry-type solar cooker for animal feed. International Journal of Sustainable Energy. 29(3), 178–184. DOI: https://doi.org/10.1080/14786461003628679

[52] Andriushchenko, K., Datsii, O., Aleinikova, O., et al., 2019. Improvement of the water resources management system at the territorial level. Problems and Perspectives in Management. 17, 421–437. DOI: https://doi.org/10.21511/ppm.17(3).2019.34

[53] Septian, W., Marimin, Herdiyeni, Y.H., Haditjaroko, L., 2016. Risk dependency chain model of dairy agro-industry supply chain using fuzzy logic approach. Supply Chain forum: an International Journal. 17(4), 218–230. DOI: https://doi.org/10.1080/16258312.2016.1232945

[54] Ali, R., Stevano, S., 2021. Work in agro-industry and the social reproduction of labour in Mozambique: contradictions in the current accumulation system. Review of African Political Economy. 49(171), 67–86. DOI: https://doi.org/10.1080/03056244.2022.1990624

[55] Zolfaghari, Z., Jones, J., 2022. A multi-variable building energy optimization: Assessing the role of energy efficient lighting technology in changing the optimal window-to-wall ratio in an office building. International Journal of Sustainable Energy. 41(11), 1819–1835. DOI: https://doi.org/10.1080/14786451.2022.2118276

[56] Buriachenko A., Levchenko K., Stetsenko B., et al., 2024. Economic unevenness of the regional development of Poland, Spain and Ukraine. Financial and Credit Activity Problems of Theory and Practice. 1(54), 331–347. DOI: https://doi.org/10.55643/fcaptp.1.54.2024.4236

[57] Salmon, P.M., Stanton, N.A., Walker, G.H., et al., 2008. Representing situation awareness in collaborative systems: A case study in the energy distribution domain. Ergonomics. 51(3), 367–384. DOI: https://doi.org/10.1080/00140130701636512

[58] Mongpraneet, S., Abe, T., Tsurusaki, T., 2004. Kinematic Model for a Far Infrared Vacuum Dryer. Drying Technology. 22(7), 1675–1693. DOI: https://doi.org/10.1081/DRT-200025628

[59] Zhao, Y.Y., Yi, J.Y., Bi, J.F., et al., 2018. Improving of texture and rehydration properties by ultrasound pretreatment for infrared-dried shiitake mushroom slices. Drying Technology. 37(3). 352–362. DOI: https://doi.org/10.1080/07373937.2018.1456449