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## The formation of a bioenergy cluster for the production of biofuels from agricultural crops and waste: the experience of Ukraine

**ABSTRACT:** Ukraine's commitments under the international framework agreements to reduce CO<sub>2</sub> emissions and the Global Climate Change Initiative provide the basis for the implementation of bioeconomy mechanisms in the country's Energy Development Strategy until 2035. One of the goals of this strategy is to reduce the consumption of fossil fuels and switch to alternative fuels. The agriculture of Ukraine is assigned the leading role in ensuring the replacement of fossil fuels with biomass of plant origin. The bioenergy potential of the agro-industrial sector of the economy requires extensive research in order to determine and integrate it into the country's energy sector. The essential characteristics of energy efficiency in the context of the cluster model of organizing the activities of enterprises for the production of biofuel as stable interactions of geographically concentrated economic entities are investigated in this article. Peculiarities of introduction of bioenergy clusters

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as stable interactions of geographically concentrated business entities (enterprises, suppliers and organizations, including scientific institutions, etc.) have been determined according to a pre-defined and agreed development strategy for all participants without exception at the stage of formation of which the competitive environment is supported taking into account the energy, ecological and socio-economic parameters of the sustainable development of territories. A model of a territorial bioenergy cluster for the production of biofuels from crops and waste was formed and the advantages of creating bioenergy clusters were analyzed. Furthermore, a matrix of a PEST analysis of the formation of bioenergy clusters in Ukraine was formed.

KEYWORDS: sustainable development, cluster, biofuel production, bioenergy, economic development

## Introduction

At the present stage of development of the Ukrainian economy, which is characterized by the strengthening of its own energy independence and diversification of the fuel and energy sector with an emphasis on the integration of renewable energy, considerable attention is paid to the study of the development of the bioenergy potential of the agricultural sector. Ensuring national energy security is one of the main principles of Ukraine's energy strategy.

Analytical studies of the bioenergy potential of the agro-industrial sector and the possibility of its integration into the fuel and energy sector of Ukraine form the basis for the further development of energy and agricultural industries and the introduction of elements of sustainable development in their organizational and economic activities.

The need to strengthen the state's energy security stimulates the creation of organizational and economic conditions for the effective development of bioenergy industry based on the resource base of agriculture. Simultaneously, the question arises of finding ways to enhance the competitiveness of the agricultural sector of the economy amid conditions of limited access to external markets for the sale of products, an increase in energy prices and dependence on oil and natural gas importing countries, which threaten the energy and economic sovereignty of the state. In addition, energy security has close ties with the economic security and development of the state, its resource potential, and national security in general.

The development of the bioenergy potential is one of the determining factors for the sustainable development of any country. Taking into account the components of the national competitiveness of Ukraine, the development of the national bioenergy potential can be considered in the context of the factors of development of innovation-oriented economies, namely, the level of business development and innovation.

In connection with the above, clusters and state cluster policy are a promising subject of research. The cluster approach as a tool for increasing the competitiveness of the functioning of individual sectors of the economy is sufficiently covered in economic sciences.

## 1. Literature review

Marshall (1993) was the first to consider clusters when studying the characteristics of industrial regions. The scientist noted a tendency towards the concentration of specialized companies in such regions. A. Marshall's theory, where enhanced effectiveness due to the proximity of similar companies was referred to as the "external economy", laid the foundation for the cluster theory.

Professor of the Harvard School, Michael Porter, who is one of the most respected authors of the concept of competitiveness strategy, is recognized as the founder of cluster theory. According to Porter (1998), clusters are an organizational form of consolidating the efforts of stakeholders aimed at achieving competitive advantages, in the conditions of the formation of a post-industrial economy. Michael Porter believed that the main advantage of the cluster model is that promising competitive advantages are created not outside, but in domestic markets, which in turn, makes it possible to positively affect the security and stability of the country's economic growth.

International organizations have also contributed to the definition of cluster. The United Nations Industrial Development Organization (UNIDO), defines cluster as "geographical concentrations of inter-connected enterprises and associated institutions that face common challenges and opportunities" (UNIDO 2001). The European Commission gives a similar definition of this category: "Clusters are groups of specialized enterprises – often SMEs – and other related supporting actors that cooperate closely together in a particular location" (European Commission 2002).

In the general model of production-cooperation and interactions of business entities, an important feature of the cluster is the factor of innovation orientation. The vast majority of clusters are formed where there is an "innovative breakthrough" in the field of machinery and production technology and subsequent entry into new markets (Burkovsky 2012).

Voynarenko and Bereza (2013) believe that building a chain of innovation in the economy ("enterprise – cluster – region – state"), on the one hand, allows the identification of sources of innovative development and also determining the place of cluster policy in the implementation of innovative development of the region. This algorithm indicates that the basis of innovative development of regions is the level of implementation of innovative developments by groups of interconnected enterprises, which determine the specifics of economic development of a particular area.

The cluster form of organizing innovative activities leads to the creation of a special form of innovation – an aggregate innovative product. Such innovation is the product of the activities of enterprises and research institutions, which allows them to accelerate their dissemination in a network of interconnections in a common regional economic space (Mytsiuk 2011).

In modern economic processes, the leading positions are occupied by clusters and systems of relationships between firms and organizations. The main goal of the cluster is to increase the competitiveness of its members in domestic and foreign markets through commercial and non-

commercial cooperation, research and innovation, education, training and policy support activities with maximum consideration of the market mechanism. The highest efficiency of clusters is achieved when they are created on the initiative from the bottom up, i.e. when the companies themselves feel the need to unite in a cluster in order to increase their competitiveness (Kaletnik et al. 2021).

Kaletnik (2010) considers the cluster of biofuel production as a stable territorial-intersectoral partnership, which is united by an innovative program of application of modern production, engineering and management technologies in order to increase the competitiveness of its participants. Goncharuk (2020) positions clusters in biofuel production as institutional models of resource consolidation to achieve the preconditions for the energy independence of the agro-industrial complex.

The work of Melnyk (2021), is important in term of developing biofuel clusters in Ukraine; it is devoted to the theoretical and practical bases of sustainable international certification systems which are regulated for biofuel producers in the EU and Ukraine. The author gives practical recommendations on the organizational and economic basis for the development of certified biofuel production in Ukraine.

The paper is the continuation of the research of the authors regarding the socio-economic and environmental importance of developing biofuels (Pryshliak et al. 2021) and the strategic potential of agricultural waste as a feedstock for biofuel production in Ukraine (Tokarchuk et al. 2021). Additionally, in depth research of the potential, awareness, and current state of agricultural waste use to ensure the energy autonomy of agricultural enterprises of Ukraine was conducted in order to evaluate the current situation with regard to turning waste into biofuel in Ukraine (Tokarchuk et al. 2020).

Thus, in the scientific literature, there are a number of definitions of the term “cluster”, which in some way reflect the theory and practice of clustering processes. However, despite thorough research, a unified approach to defining the concept of cluster in science has not yet been developed.

In order to study the model of a bioenergy cluster for the production of biofuels from crops and waste, there is a need for a more accurate conceptualization of what clusters or cluster associations are and their related phenomena.

## 2. Aims

The aim of the research is the theoretical and methodological substantiation and methodological improvement of the foundations of organizing a model of a bioenergy cluster for the production of biofuel from agricultural crops and waste.

This aim defines the following research targets: studying the main groups of interacting actors in the bioenergy cluster; developing a model of a territorial bioenergy cluster for the produc-

tion of biofuels from crops and waste; identifying the main advantages of the bioenergy cluster; building a matrix of PEST analysis of the formation of bioenergy clusters; identifying the main bases of state support for bioenergy clusters; identifying the stages of formation of bioenergy clusters; forming directions of the state strategy in the direction of the development of bioenergy clusters.

### 3. Materials and methods

In the writing of the article, a number of general scientific, statistical-analytical and economic-mathematical research methods were used, as well as the principles of the system approach and the clustering method.

### 4. Results and discussion

For the development of the bioenergy sector in the medium and long term perspective and for strengthening the energy independence of the Ukrainian economy, it is necessary to create bioenergy clusters according to a number of characteristics that have the greatest specific weight in the overall development of this sector.

In considering the above, it is possible to define a bioenergy cluster as a territorial organizational and production form of interaction between innovative enterprises/organizations, banking, the private sector, educational institutions, authorities and infrastructure facilities, characterized by the production of bioenergy feedstock, by-products, waste and biofuels. The bioenergy cluster is characterized by the presence of an agreed development strategy aimed at realizing the interests of each of the cluster members, and has significant food, socio-economic and energy significance for the region. Such alliances increase opportunities for technological innovation in the bioenergy sector and facilitate the negotiation of existing obstacles to the development of the bioenergy sector and bio-oriented economy.

Thus, the components of the bioenergy cluster can be: agricultural enterprises (as producers of bioenergy feedstock, food feedstock, by-products and waste); stakeholders in bioenergy development (producers of all types of biofuels and bioenergy); service infrastructure entities; educational institutions, research centers, business incubators; auxiliary facilities (consulting, leasing, legal, investment and innovation enterprises). An important link in the formation and functioning of the cluster, which to some extent may affect the structure of the cluster and its development, are the state authorities in the region and local governments.

The general structure of the cluster is a model for building cooperative ties between the subjects of the association. The main groups of interacting subjects of the bioenergy cluster are considered in Figure 1.

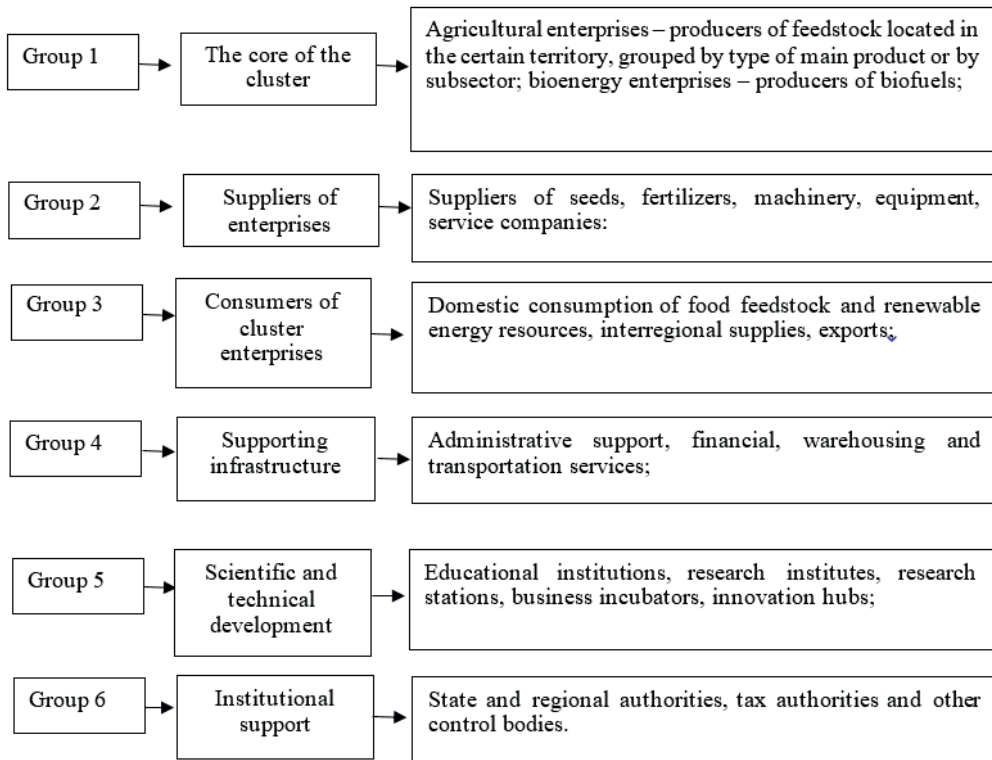


Fig. 1. Groups of interacting entities of the bioenergy cluster

Source: developed by the authors

Rys. 1. Grupy oddziałujących na siebie podmiotów klastra bioenergetycznego

Currently, the use of bioenergy resources as feedstock for biofuel production in Ukraine is becoming increasingly popular and widespread. This is due to the rise in prices for traditional energy resources (natural gas, oil, electricity), consumers' desires to use environmentally friendly energy and the presence of by-products and waste from producers (straw, sawdust, manure, etc.). At the same time, there are a number of factors that constrain the large-scale use of the bioenergy potential as an energy resource, in particular, insufficient efficiency of the technological support of the fuel production process, consumer disinterest in the transition to biofuels, imperfection of the normative-legal regulation of the bioenergy sphere and the lack of developed logistics schemes.

Creating a specialized bioenergy cluster for the production of biofuels from crops and waste has the potential to ensure the maximum efficiency of the natural resource potential (land,

feedstock, by-products, waste), provide consumers with environmentally friendly energy resources and, at the same time, play a role in innovation development, which would contribute to the reorientation to an innovative model of regional development. In particular, according to the latest studies of the Bioenergy Association of Ukraine, the potential of energy production from biomass in Ukraine is 23 million t.e. The main components of this potential include crop by-products (a total of 10 million tons of biomass or 44% of the total biomass potential) and energy crops (a total of 7.5 million tons of biomass or 32% of the total potential). By-products of crop production include grain and rapeseed straw, corn stalks, sunflowers, etc. Energy crops include willow, poplar and miscanthus for solid biofuel and corn for biogas. The production potential of biogas/biomethane in Ukraine for fermentation technology is estimated at 9.7 billion cubic meters of methane/year. This is about 1/3 of all natural gas consumption in Ukraine and is practically equal to the annual import of natural gas into the country (Bioenergy Association of Ukraine 2022).

Based on the above, we propose the following model of the territorial bioenergy cluster of biofuel production from crops and biowaste (Fig. 2).

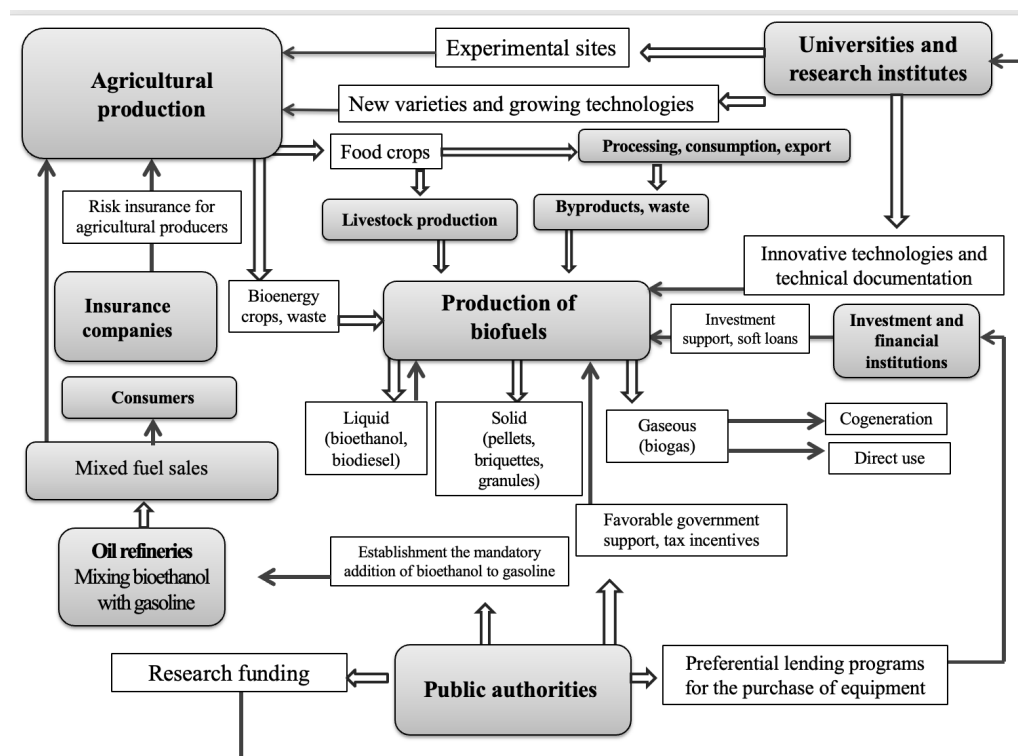


Fig. 2. Model of territorial bioenergy cluster of biofuel production from crops and waste

Source: developed by the authors

Rys. 2. Model terytorialnego klastra bioenergetycznego do produkcji biopaliw z upraw i odpadów

When increasing the volume of biofuel production, it is important to take into account the need to balance the use of crops as bioenergy feedstock and as food products (including animal feed). After all, it is extremely important to ensure both energy and food security. Their interconnectedness and interaction in the use of crops cannot be underestimated. Considering the volume of agricultural production today, it can be emphasized that Ukraine not only produces a sufficient amount of food, but also directs part of their volume for export.

It is also important that Ukraine is an agrarian state, and this once again emphasizes the advantages of Ukraine over other countries in the development of bioenergy clusters. Significant areas of currently unused agricultural land, high crop yields, interest of national producers and the growing demand for biofuels create a favorable climate for the development of bioenergy clusters in Ukraine.

In order to develop the bioenergy potential of Ukraine and as a consequence of the bioeconomy as a new direction in the economy, the idea of creating bioenergy clusters is a new approach to conducting not only the region's economy but also the national economy. In world practice, it is concluded that the level of profitability of agriculture will depend on the level of implementation in the regions of agro-bioenergy clusters (Talavyria et al. 2017).

The cluster approach enables increasing the efficiency of interaction of agricultural producers, processing enterprises, producers of "green" energy, the private sector, financial institutions, the state, research and educational institutions in the innovation process. Therefore, the creation of a bioenergy cluster for the production of biofuels from crops and biowaste will have a number of benefits for all participants in the cluster. The main advantages of the bioenergy clusters are shown in Figure 3.

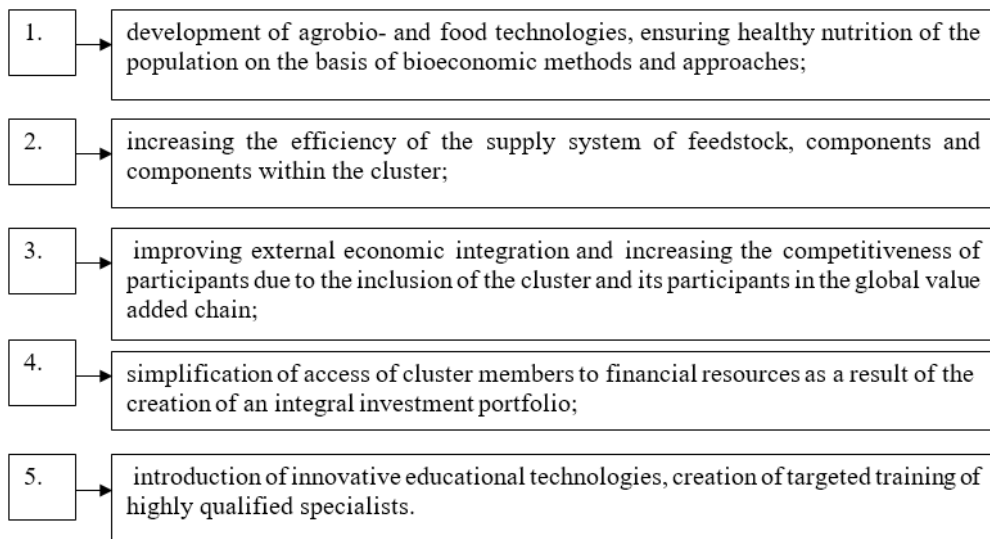


Fig. 3. Advantages of creating bioenergy clusters

Source: developed by the authors

Rys. 3. Korzyści z tworzenia klastrów bioenergii



Identifying and defining the benefits of a potential cluster in each industry is different, as each type of cluster association has its own characteristics, opportunities, priorities for economic growth and certain characteristics of cluster members.

As world experience shows, cluster associations are one of the most effective forms of organizing innovative processes, improving the socio-economic development of regions, improving the quality of scientific and technical developments and innovations, increasing the efficiency of using natural resource potential, and strengthening the country's competitiveness and defense capability. This is due to the fact that the market is no longer competing with individual enterprises but with their aggregate, which reduces their costs due to the joint technological chain and cooperation of companies.

In the conditions of Ukraine, bioenergy clusters should be considered as a qualitatively new form of management and organization of complex production activities as well as an important component of the implementation of an innovative model of economic development of regions, taking into account the specifics of Ukrainian economic and management systems as well as providing appropriate legislative and regulatory support.

Considering the prospects for the development of bioenergy in Ukraine, it should be noted that the creation of a cluster association of enterprises in this industry would be a significant achievement that can strengthen the competitiveness of cluster members and guarantee national energy security. The bioenergy cluster of biofuel production from crops and biowaste is created with a favorable combination of both positive and negative factors. To summarize all the positive and negative political, economic, social and technological factors influencing the formation of the bioenergy cluster, we can present a matrix of PEST analysis (Table 1).

TABLE 1. Matrix of PEST analysis of the formation of bioenergy clusters

TABELA 1. Macierz analizy PEST powstawania klastrów bioenergii

Political	P	Economic	E
<p>Positive</p> <ol style="list-style-type: none"> <li>1. Activity of young and highly qualified staff and ambition to create positive changes;</li> <li>2. Effective policy towards decentralization;</li> <li>3. Support of international organizations and partner countries;</li> <li>4. European vector of development and readiness to adapt Ukrainian legislation to EU requirements.</li> <li>5. Changes in legislation that strengthen the fight against corruption reduce of bureaucratization.</li> </ol> <p>Negative</p> <ol style="list-style-type: none"> <li>1. Imperfection of the regulatory framework in the field of bioenergy;</li> <li>2. Political instability and the consequences of revolutionary events;</li> <li>3. The military conflict in eastern Ukraine and the annexation of Crimea;</li> <li>4. Bureaucratization, corruption and lobbying of certain political groups.</li> </ol>		<p>Positive</p> <ol style="list-style-type: none"> <li>1. Gradual recovery from the economic crisis; insignificant but stable GDP growth;</li> <li>2. Investment attractiveness of the national economy and regions.</li> </ol> <p>Negative</p> <ol style="list-style-type: none"> <li>1. Fluctuations in the exchange rate of the national currency (inflation);</li> <li>2. The predominance of exports of raw materials and imports of finished products;</li> <li>3. High level of unemployment in the country, especially in rural areas;</li> <li>4. Uncertainty of land relations;</li> <li>5. The country's energy dependence on energy imports;</li> <li>6. Constant rise in energy prices;</li> <li>7. Lack of interest of financial institutions and investors in supporting innovative projects.</li> </ol>	

TABLE 1. cont

TABELA 1. cd.

Social	S	Technological	T
<p style="text-align: center;">Positive</p> <p>1. Availability of labour resources and qualified labour force; 2. High level of secondary and higher education in the country.</p> <p style="text-align: center;">Negative</p> <p>1. An aging nation, an increase in the number of elderly people; 2. Migration processes, departure of the able-bodied population and youth abroad; 3. Urbanization; 4. Problems with finding a job in rural areas; 5. Slow development of infrastructure in rural areas; 6. Low incomes of the population and low purchasing power for the introduction of new technologies (for example, individual biogas plants, solar panels).</p>		<p style="text-align: center;">Positive</p> <p>1. Automation and mechanization of all production processes, the rapid development of scientific and technological progress, the availability of “know-how”; 2. Strengthening the protection of intellectual property rights; 3. Technological kinship of certain economic entities operating for the sake of a common end result; 6. Geographic proximity of a number of business entities that are technologically and economically related; 7. Development of communication and information technologies.</p> <p style="text-align: center;">Negative</p> <p>1. Lack of communication between science and technology in the real sector of the economy; 2. Lagging of education in higher education from innovation processes; 3. Lack of financial support from the state for science and innovation; 4. Inconsistency of certain products in the field of bioenergy with world standards, insufficient consideration of the world market situation.</p>	

Source: developed by the authors.

It should be noted that the introduction of innovative bioenergy clusters is impossible without a favorable investment climate and stable government support which integrates the political, legal, financial, scientific and technological communication tools aimed at creating conditions for the development of innovative processes and stimulating the implementation of the results of innovative activities in production. State support for bioenergy clusters should be formed on the basis of the following blocks: forming, regulating, implementing and controlling (Fig. 4).

At the same time, the formation of each block should take into account the basic principles of state support for innovation clusters, including complexity, targeting, legitimacy, objectivity and equivalence.

Among the various approaches to the organization and functioning of clusters, the processes of interaction between business and government have always been considered dominant. Local governments are entrusted with the mission of improving the infrastructure for the needs of innovative business and the coordination of interaction within the created innovation formation.

The functioning and development of clusters in most countries are ensured by various direct and indirect methods of state support, which stimulate regional development through increased employment, budget allocations at various levels, higher wages, and the sustainability and competitiveness of regional production. State support for innovation clusters in different countries of the world is mainly aimed at intensifying the scientific and technical activities of clusters

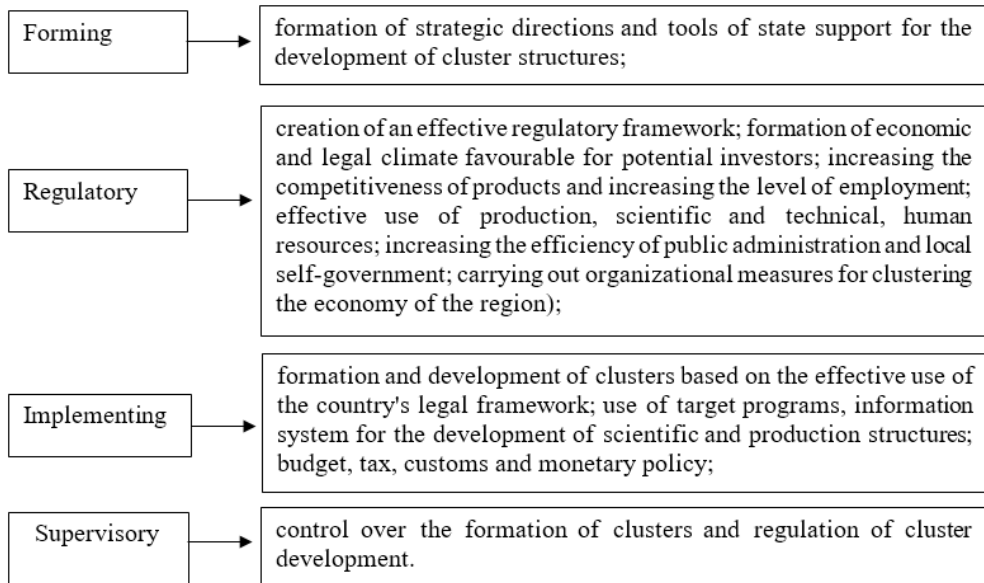


Fig. 4. Basic bases of state support of bioenergy clusters

Source: developed by the authors

Rys. 4. Główne podstawy państwowego wsparcia klastrów bioenergii

by: increasing funding for their innovation activities; creating high-tech competitive products; production that takes into account the situation on the world market; integrating research and development into the global innovation system; promoting international partnerships in the field of innovation.

The most significant factor is state support at the stage of cluster development rather than creation, as it is difficult to influence the desire of potential participants to become members of the cluster and the creation of stimulating favorable conditions requires significant financial resources. At the stage of cluster development, when it has already proven its viability, government support can become a stimulating lever for its development. Stages that can affect the increase in the competitiveness of the economy based on bioenergy clusters are described in Figure 5.

Further measures of state support for the development of bioenergy clusters should be those that will ensure equal access for participants to the market of feedstock and biofuels; support for the production and use of domestic bioenergy equipment; provision of state support for scientific research; formation of a favorable institutional climate for the implementation of projects of advanced bioenergy technologies.

The effective implementation of all stages of the state strategy towards the development of bioenergy clusters will accelerate the expected result of increasing their number in Ukraine and demonstrate the positive impact of bioenergy clusters on economic growth, enhancing energy security and improving the environmental situation.

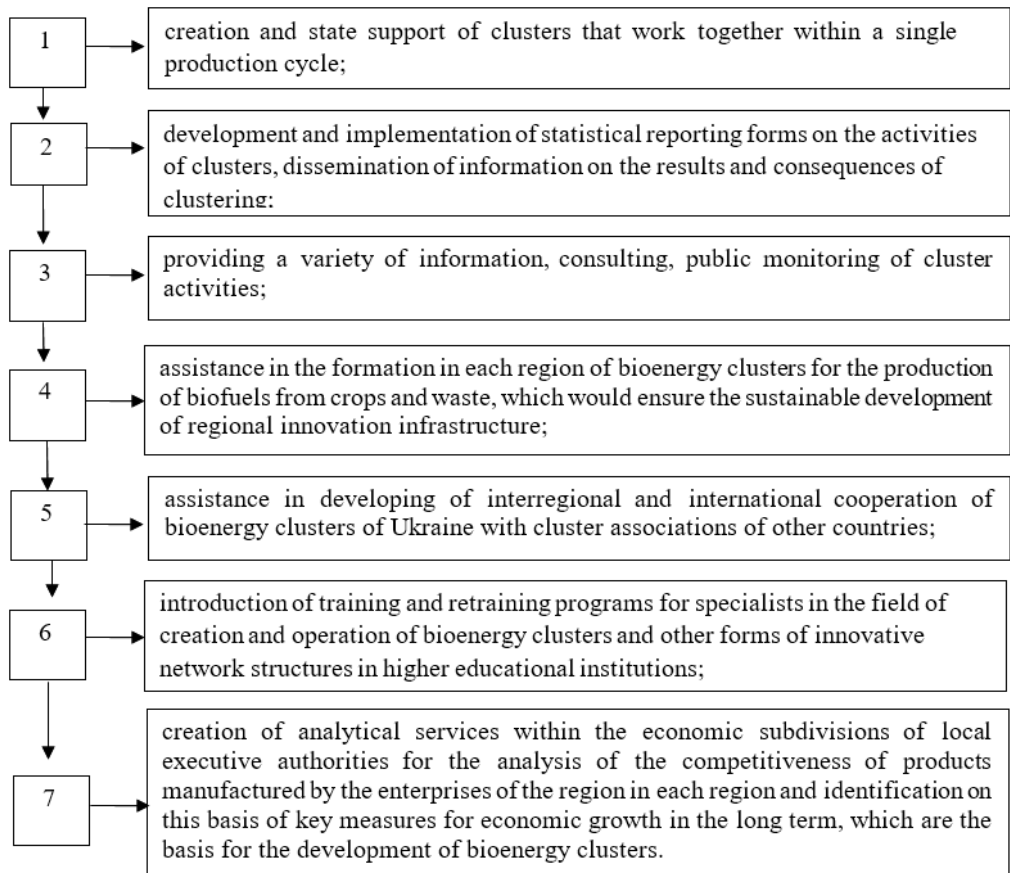


Fig. 5. Directions of the state support strategy towards the development of bioenergy clusters  
 Source: developed by the authors

Rys. 5. Kierunki strategii wsparcia państwa zmierzające do rozwoju klastrów bioenergii

It is also important to comply with certain stages of the implementation of the bioenergy cluster model. In particular, it is important to: identify competitive enterprises – potential cluster members; search for opportunities to attract investment; define the relationship between the participants in the innovation process; conduct economic and statistical modelling of the effectiveness of the future cluster. We propose conducting planning in the following stages (Fig. 6).

World practice shows that the functioning of the most successful economic systems is almost completely ensured by the advantages in production and management technologies. Therefore, the development of an economic system of any level is possible with the integrated use of the concepts of strategic management, taking into account the processes that determine the specifics of the current stage of economic development.

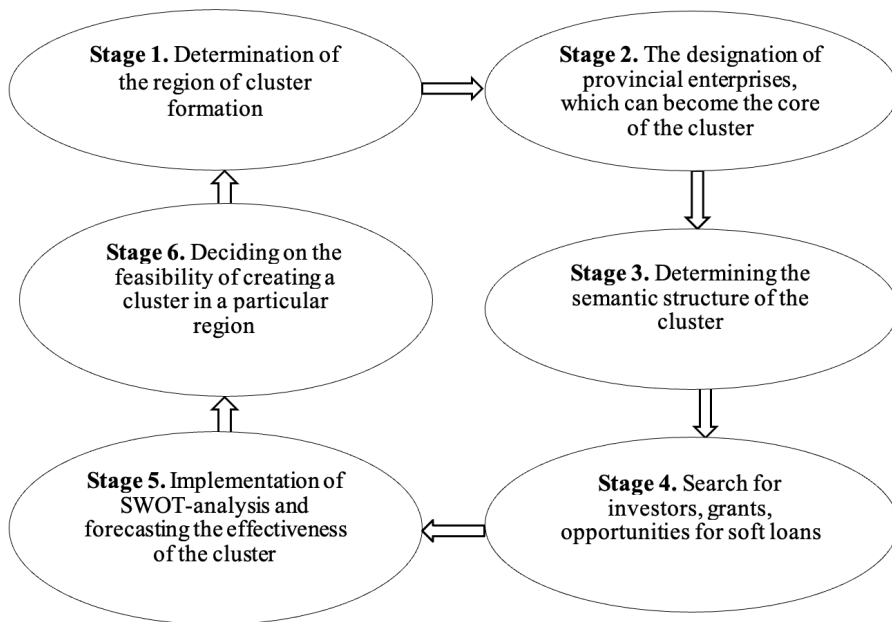


Fig. 6. Stages of formation of bioenergy clusters

Source: developed by the authors

Rys. 6. Etapy powstawania klastrów bioenergii

## Conclusions

At the present stage of economic development, cluster strategies are widely used throughout the world. In formulating cluster policy, public authorities in developed countries advocate a broad classification of clusters in order to include as many participants as possible.

Cluster modelling has great potential in the agricultural sector, which is strategically important for the state and can play a significant role in ensuring the country's energy security. The formation of a cluster depends on the degree of its openness, which is determined by the possibility of using internal sources of financing in the region, the full use of the available resources and the reliability of their distribution channels. The use of the bioenergy potential of agricultural enterprises, being one of the mechanisms of sustainable development, is intended not only to increase the efficiency of agro-industrial production but also to ensure a gradual decrease in the negative impact of economic activities on the environmental impact.

To increase the dynamics of the growth of technical and economic indicators of bioenergy clusters in Ukraine at the state level, it is necessary to introduce direct financial incentives

and the provision of concessional government loans, the financing of basic innovations in the manufacturing sector and the ensuring of innovations in the non-market sector based on the experience of foreign countries. It is advisable to develop a state program for organizing and financially stimulating bioenergy clusters together with the interested ministries in order to ensure the creation of regional innovation networks.

The formation of a bioenergy cluster for the production of biofuels from agricultural crops and biowaste in Ukraine creates a number of advantages, in particular, the most efficient use of agricultural feedstock, by-products and biowaste, effective interaction between government authorities and business structures, increases in the level of efficiency of small enterprises, the maximization of profits, increases in volumes of tax revenues to budgets, strengthening of the energy security of the state, improvements to the ecological state, and the creation of opportunities for entering foreign biofuel markets.

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## Powstanie klastra bioenergetycznego do produkcji biopaliw z upraw rolnych i odpadów: doświadczenia Ukrainy

### Streszczenie

Zobowiązania Ukrainy wynikające z międzynarodowych umów ramowych dotyczących redukcji emisji CO<sub>2</sub> oraz Global Climate Change Initiative stanowią podstawę do wdrożenia mechanizmów bio-gospodarki w Strategii Rozwoju Energetycznego kraju do 2035 roku. Jednym z celów tej strategii jest ograniczenie zużycia paliw kopalnych i przejście na paliwa alternatywne. Rolnictwu Ukrainy przypisuje się wiodącą rolę w zapewnieniu zastąpienia paliw kopalnych biomasą pochodzenia roślinnego. Potencjał bioenergetyczny sektora rolno-przemysłowego gospodarki wymaga szeroko zakrojonych badań w celu jego określenia i zintegrowania z energią kraju. W artykule zbadano podstawowe cechy efektywności energetycznej w kontekście klastrowego modelu organizacji działalności przedsiębiorstw do produkcji biopaliw jako stabilnych interakcji geograficznie skoncentrowanych podmiotów gospodarczych. Specyfika wprowadzania klastrów bioenergetycznych jako stabilnych interakcji skupionych geograficznie podmiotów gospodarczych (przedsiębiorstw, dostawców i organizacji, w tym instytucji naukowych itp.) została określona zgodnie z wcześniej zdefiniowaną i uzgodnioną strategią rozwoju dla wszystkich bez wyjątku uczestników, na etapie której wspierane jest kształtowanie konkurencyjnego otoczenia z uwzględnieniem parametrów energetycznych, ekologicznych i społeczno-ekonomicznych zrównoważonego rozwoju terytoriów. Stworzono model terytorialnego klastra bioenergetycznego do produkcji biopaliw z upraw i odpadów oraz przeanalizowano zalety tworzenia takich klastrów. Ponadto utworzono matrycę analizy PEST powstawania klastrów bioenergetycznych na Ukrainie.

SŁOWA KLUCZOWE: zrównoważony rozwój, klastry, produkcja biopaliw, bioenergia, rozwój gospodarczy

