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THE DEVELOPMENT AND SIGNIFICANCE OF INDUSTRIAL SYMBIOSIS IN UKRAINE

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THE DEVELOPMENT AND SIGNIFICANCE OF INDUSTRIAL SYMBIOSIS IN UKRAINE

Volodymyr Davydenko, Olga Karpun. *«The development and significance of industrial symbiosis in Ukraine».* The article comprehensively investigates the stages of development and current trends of industrial symbiosis in Ukraine, analyzing its role in shaping the foundations of the circular economy and the post-war economic recovery. It highlights the main advantages of symbiosis for Ukrainian industrial enterprises, ranging from the reduction of production costs and the creation of new sources of income to the improvement of environmental safety in manufacturing and increased competitiveness in international markets. Particular attention is paid to the interaction between business, communities, local authorities, and the experience of implementing eco-industrial parks in different regions of the country. The main barriers – technological, infrastructural, legislative, and motivational – that constrain the development of industrial symbiosis are outlined, and the prospects for further scaling this model are substantiated, taking into account the specifics of the national economy and contemporary global trends in sustainable development. The article contains practical recommendations for improving the development of infrastructure and mechanisms for stimulating cooperation within symbiotic networks.

Keywords: industrial symbiosis, resource efficiency, environmental friendliness, circular economy

Володимир Давиденко, Ольга Карпунь. *«Становлення та значення промислового симбіозу в Україні».* У статті комплексно досліджено етапи становлення та сучасні тенденції

промислового симбіозу в Україні, з аналізом його ролі у формуванні засад циркулярної економіки та післявоєнного відновлення економіки держави. Висвітлено основні переваги симбіозу для українських промислових підприємств - від зниження виробничих витрат і утворення нових джерел доходу до підвищення екологічної безпеки виробництва та конкурентоспроможності на міжнародних ринках. Особливу увагу приділено взаємодії бізнесу, громад, органів місцевого самоврядування, а також досвіду впровадження еко-індустріальних парків у різних регіонах країни. Окреслено основні бар'єри – технологічні, інфраструктурні, законодавчі та мотиваційні – що стримують розвиток промислового симбіозу, а також обґрунтовано перспективи подальшого масштабування цієї моделі з урахуванням специфіки національної економіки й сучасних глобальних трендів сталого розвитку. Стаття містить практичні рекомендації щодо удосконалення розвитку інфраструктури та механізмів стимулювання співпраці в межах симбіотичних мереж.

Ключові слова: промисловий симбіоз, ресурсоефективність, екологічність, циркулярна економіка

Introduction. Industrial symbiosis is one of the essential tools for implementing a circular economy, which replaces the traditional linear "take-make-dispose" model with a closed-loop system. In this system, the waste of one enterprise becomes a valuable raw material for another. This approach is crucial for the transition to sustainable development, combining economic efficiency with environmental responsibility.

Industrial symbiosis is an integral part of industrial ecology, based on the principle of cooperation between industries that traditionally operate separately. The core idea is the exchange of materials, energy, water resources, and by-products between enterprises. This concept follows the laws of natural ecosystems, where the waste of one organism serves as a source of resources for another, forming closed cycles with minimal losses.

Industrial symbiosis is defined as integration between different enterprises, in which they share resources, energy flows, or residual products. Such cooperation contributes to the creation of industrial ecosystems with closed loops of material and energy flows. As a result, the efficiency of production processes increases, the negative environmental impacts decrease, and new economic ties develop.

The implementation of industrial symbiosis systems helps reduce enterprises'

costs for energy and material resources through rational resource exchange and waste reuse, which directly enhances their competitiveness. This approach leads to a significant reduction in industrial waste and pollution, supporting the circular economy, and promotes sustainable development solutions. The emergence of new business models and cluster cooperation opens up access to additional sources of income and innovative partnerships, as well as creating additional jobs.

Analysis of recent studies and publications. Ukrainian and foreign scientists are researching the topic of industrial symbiosis, developing both theoretical foundations and practical cases of applying this approach for the transition to a circular economy and sustainable development.

The problems of integration between different enterprises, in the process of which they jointly use resources, are considered in foreign and domestic works by scientists, including V. Dykan [1], M. Melnikova [2], T. Domenech, R. Bleischwitz, Marian Chertow, T. Domenech, R. Bleischwitz, A. Doranova, D. Panayotopoulos, L. Roman [3].

The studies conducted prioritize the environmental impact of industrial symbiosis with its associated benefits, including the conservation of local resources and the social consequences associated with improving living conditions.

Identification of previously unresolved parts of the overall problem. Ukrainian industry requires renewal, resource optimization, and the implementation of ecological standards during infrastructure reconstruction.

The growing shortage of primary resources and energy carriers, as well as environmental challenges, necessitates seeking models for the effective utilization of all types of flows. Therefore, industrial symbiosis is strategically important for the sustainability of the country's economy.

For regions with strong industrial traditions, long-term synergistic exchange allows for the development of local clusters and the attraction of foreign investment, stimulating recovery and sustainable development.

The development of eco-industrial parks and integration into European circular economy chains strengthens Ukraine's position in the global market and prepares industries for future environmental requirements.

Formulation of the article's objectives. The purpose of the study is to analyze and develop proposals for the introduction of industrial symbiosis within the context of sustainable development.

Presentation of the main research material. Industrial symbiosis is a model of collaborative economy where enterprises exchange resources, waste, and services to increase efficiency and reduce environmental impact. A key feature is the exchange of by-products flows, where one company's waste, by-products, energy (such as heat), water, or chemicals are utilized by others as raw materials, thus avoiding disposal and reducing the need for primary resources. This model is based on a collaborative network involving several companies, often from different industries, at the regional or cluster level, coordinated through platforms or organizations such as regional hubs. This coordination includes the exchange of information, technology, and infrastructure. Economic efficiency is realized through the

reduction of costs associated with raw materials, energy, and disposal, which increases profitability and creates new sources of income, for example, through the sale of waste as raw materials. Environmental sustainability is achieved by reducing waste, CO₂ emissions, and pollution, promoting a circular economy where resources are reused, and helping to achieve the UN's Sustainable Development Goals (SDGs).

Innovativeness and flexibility stimulate the development of new technologies for purification or processing of waste, as well as new business models, allowing the network to adapt to market changes. Social and regional integration supports local communities through job creation, infrastructure development, and increased regional competitiveness, which requires trust, contracts, and regulatory support. Finally, scalability allows for starting with a small number of businesses and expanding to industrial parks or national networks, making industrial symbiosis a powerful tool for transitioning to a green economy.

Industrial symbiosis is viewed as an integrated model of interaction between enterprises aimed at increasing resource utilization efficiency through the smooth exchange of material, energy, and water flows and the shared use of infrastructure. One of the basic characteristics of industrial symbiosis is the geographical proximity of participants, which contributes to the optimization of logistics costs and ensures the convenience of resource exchange; at the same time, this feature is not mandatory, but it enables the formation of more sustainable interaction networks.

Open communication and trusting relationships between the parties are critical factors for the success of symbiotic relationships, as only effective cooperation can lead to sustainable mutual benefits. The participation of companies from different sectors of the economy helps broaden the spectrum of potential exchanges, forming cross-sectoral interaction, which, in turn, leads to the widespread implementation of

innovative solutions. Innovativeness is manifested, in particular, in the development of new approaches to by-product processing and the creation of technologies for their secondary use.

All decisions regarding the organization of industrial symbiosis must meet the criteria of economic feasibility for each participant, as financial effectiveness is precisely what ensures the motivation of enterprises to participate in exchange processes and integrate into symbiotic networks.

The implementation of circular economy principles within the framework of industrial symbiosis occurs through the transformation of waste into resources, which minimizes the consumption of primary materials. Exchange mechanisms include [4,5]:

- material exchange, in which by-products (slag, ash, gypsum, biomass, etc.) become raw materials for other production processes,
- energy exchange (transfer of excess heat, steam, or electricity between enterprises),
- water exchange (use of treated wastewater for technological or cooling purposes),
- shared use of infrastructure (collective use of treatment systems, pipelines, and equipment).

Thus, industrial symbiosis creates a powerful tool for implementing sustainable production models, integrating environmental and economic goals, generating added value by optimizing resource flows, and strengthening the competitiveness of enterprises within the circular economy.

The main tool is the creation of eco-industrial parks – specially organized areas where enterprises collaborate to solve environmental and resource challenges. These parks include infrastructure that facilitates resource sharing, centralized treatment systems, and digital platforms designed to identify opportunities for cooperation.

The economic benefits of industrial symbiosis are significant and multifaceted, which makes it highly attractive to business. First of all, it reduces costs by decreasing the volume of primary raw materials purchased and lowering waste disposal costs. In addition, by-products previously perceived as waste can become new sources of income – they are sold or used to create new products, forming new business models and market opportunities.

The use of industrial symbiosis leads to increased resource efficiency: the utilization of energy, water, and materials is optimized, which translates into higher productivity and enterprise competitiveness while simultaneously reducing the negative environmental impact.

Industrial symbiosis is a crucial component of the modern economic development model, allowing enterprises to achieve significant economic, environmental, and social benefits within the circular economy. The primary stimulus for businesses is cost reduction – using by-products as secondary raw materials reduces resource procurement expenditures and waste disposal costs. By-products, previously seen as liabilities, are transformed into sources of income: they can be sold or utilized for the development of new products, opening up new opportunities for companies in the market.

Optimizing the use of energy, water, and materials increases overall resource efficiency, which translates into increased productivity, reduced environmental impact, and improved competitiveness. Additionally, establishing symbiotic relationships reduces dependence on unstable external markets and raw material price volatility, which is critical for businesses in times of geopolitical instability and resource scarcity [6].

The environmental benefits of industrial symbiosis are reflected in a significant reduction in greenhouse gas emissions, thanks to reduced demand for new materials and more efficient energy use.

Reusing materials reduces the extraction of primary raw materials, which helps to conserve natural resources, especially scarce and non-renewable ones. Waste is transformed into resources, which significantly reduces the amount of materials sent to landfills or incinerated – materials remain in economic circulation for as long as possible. The exchange of water and energy resources ensures rational use and reduces overall consumption in industrial regions [7].

The social and innovative effects of implementing industrial symbiosis are equally important. The exchange of resources between enterprises from different industries creates favorable conditions for cross-sector cooperation, stimulates cross-fertilization of ideas, accelerates the development of new products, and leads to unexpected technological solutions. The development of circular industry sectors, such as recycling, remanufacturing, and waste management, contributes to the creation of new jobs and the improvement of professional skills, diversifying the economy and strengthening social capital. Successful industrial symbiosis initiatives attract investment, stimulate employment, promote the formation of circular economy clusters, and create a favorable environment for businesses focused on sustainable development. Active participation of companies in resource efficiency and waste reduction programs improves their corporate image, increases customer loyalty, and facilitates access to environmentally oriented financing.

Thus, industrial symbiosis integrates economic, environmental, and social aspects, creating added value and ensuring the sustainable development of businesses and regions.

Despite its numerous advantages, industrial symbiosis faces significant challenges that limit its widespread implementation. One of the most significant obstacles remains the lack of trust between partners – companies are often reluctant to share production information and waste data due to confidentiality concerns.

Insufficient technological and infrastructural readiness also plays a significant role: the lack of specialized equipment, transport, and processing systems complicates the implementation of symbiotic networks. The lack of financial incentives and regulatory support from the state reduces the motivation of enterprises to participate in symbiosis, and fluctuations in the quality and volume of by-products create additional risks for investors and disrupt the stability of supply chains. The increase in transaction costs associated with coordination, partner search, and exchange system setup requires improvements in waste pricing models, strengthening the role of industry associations, and taking into account the territorial location of enterprises.

Industrial symbiosis is of strategic importance for the circular economy, as it is not only a tool for reducing waste, but also the foundation for the systemic transformation of industrial ecosystems. The implementation of the key principles of the circular economy – maximizing resource value, eliminating waste, and regenerating natural systems – allows for the formation of more sustainable and adaptive economic models. Symbiotic networks, eco-industrial parks, and cross-sector clusters expand the possibilities for scaling circular solutions, providing a multiplier effect and systemic impact at the regional and national levels. The experience of successful cases, such as the Kalundborg symbiosis in Denmark or various international initiatives, acts as a catalyst for the global expansion of industrial symbiosis practices [8].

For Ukraine, industrial symbiosis is particularly important in the context of post-war recovery, European integration, and changing economic priorities. Saving primary resources is one of the most important advantages in the post-war period, when there is an urgent need to increase resource efficiency and optimize infrastructure reconstruction. The implementation of a circular economy creates conditions for transformation of the national economy into

a more sustainable and environmentally friendly one, contributes to the conservation of valuable resources, the development of new employment sectors, and the increase in competitiveness for both individual enterprises and the country as a whole. The transition to circular economy models is an important step for Ukraine on its path to European integration and sustainable post-war growth. The recycling of industrial waste into building materials, the combination of symbiotic solutions with smart specialization of urban projects and urban planning allow for the most effective utilization of the symbiosis potential for saving primary resources during reconstruction.

Conclusions. In summary, industrial symbiosis is a central element of the circular economy, transforming production waste into valuable resources, stimulating innovation, creating new economic opportunities, and providing significant environmental and social benefits. It is not only a method of resource optimization, but also a systematic approach to building a more sustainable, competitive, and environmentally responsible industry, which is crucial important for the global transition to sustainable development.

Industrial symbiosis is gradually becoming one of the leading trends in the development of the modern economy, introducing innovative approaches to resource utilization, stimulating cooperation between enterprises, reducing waste, and simultaneously opening up new economic prospects. The practices of advanced countries and the application of symbiotic models demonstrate that this strategy

provides significant economic benefits, including reduced costs, increased competitiveness, optimization of material, energy and water consumption, and the creation of additional sources of income. At the same time, industrial symbiosis plays an important role in environmental protection by contributing to the reduction of emissions, waste, and the conservation of natural resources, which is fully aligns with the principles of the circular economy.

For Ukraine, the implementation of industrial symbiosis is extremely relevant in the context of post-war reconstruction, economic modernization, and integration into the European economic space. The creation of sustainable symbiotic networks between enterprises from different industries will not only save scarce natural resources and reduce environmental impact, but also generate additional competitive advantages for Ukrainian producers in European and global markets. To unlock this potential, it is necessary first and foremost to strengthen trust between business partners, develop infrastructure, ensure state support for innovation, and improve the regulatory framework in accordance with the needs of the circular economy.

The large-scale implementation of industrial symbiosis in Ukraine can become a powerful catalyst for the systematic modernization of the national economy. The transition from the traditional linear model to a resource-efficient and sustainable development strategy will facilitate the country's integration into contemporary global trends and meet the requirements of sustainable development.

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