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CIRCULAR ECONOMY AS THE ECONOMIC BASIS OF THE INDUSTRY 5.0 PARADIGM

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ABSTRACT

The article explores the role of the circular economy as the economic basis of the Industry 5.0 paradigm and justifies its importance for the implementation of the principles of human-centricity, sustainability and resilience of industrial development. It is shown that the integration of closed material and energy cycles allows to reconcile technological innovations with environmental responsibility and social value of production. The function of digital technologies of Industry 5.0 as tools for managing circular processes throughout the product life cycle is analyzed. The feasibility of considering the circular economy not as an auxiliary environmental practice, but as a systemic economic foundation of a new industrial paradigm is substantiated. The results obtained form the basis for further research in the field of digital transformation of sustainable production.

Keywords: Industry 5.0, Circular Economy, Human-Centricity, Sustainability, Resilience, Digital Technologies, Closed Resource Cycles.

1. INTRODUCTION

The modern transformation of industry is characterized by the transition from an exclusively technologically oriented paradigm to a human-centric, sustainable and socially responsible development model, called Industry 5.0. Within this paradigm, production efficiency is no longer considered an end in itself, but is assessed in relation to environmental safety, resource sustainability and social benefit. At the same time, the preservation of the linear economic model "extraction-production-consumption-waste" comes into conflict with the goals of sustainable development and the limited natural resources. This necessitates the search for economic mechanisms capable of ensuring the coordination of technological progress with environmental and social requirements. The circular economy in this context is considered as an alternative model based on closed cycles of material use, waste minimization and extension of the product life cycle. Its integration into Industry 5.0 allows not only to reduce the resource burden on the environment, but also to form new human-oriented and socially significant business models. The development of digital technologies, in particular digital twins, intelligent control systems and sensor networks, creates the prerequisites for the effective implementation of circular processes in real production. Thus, Industry 5.0 acts as a technological platform, while the circular economy forms its economic and value basis. However, scientific research still lacks a systematic analysis of the economic role of the circular model in the architecture of Industry 5.0. This makes it relevant to study the relationship between these concepts as a single socio-technical and economic system. Substantiating such an approach allows us to rethink not only the methods of production, but also the goals of industrial development in general. The prerequisites for such reasoning are the depletion of natural resources, the growth of environmental risks, the change in social values towards sustainable development, and the emergence of technological tools for managing closed economic cycles.

2. CIRCULAR ECONOMY AS AN INTEGRAL PART OF INDUSTRY 5.0

The current stage of industrial development is characterized by a gradual transition from technologically oriented models to more complex socio-technical and economic systems. Within these systems, technical progress is viewed through the prisms of public benefit and environmental responsibility. In this context, the concept of Industry 5.0 is being formed as a new paradigm of industrial development, focused on human-centricity, sustainability and resilience. It involves the use of digital and intelligent technologies not only to increase production efficiency, but also to ensure harmonious interaction between man, machine and environment. Such an approach requires rethinking not only the technological, but also the economic principles of the functioning of industrial systems. In this sense, the circular economy plays a key role as a model based on the closure of resource flows, waste minimization and extension of the product life cycle. It is it that creates the economic prerequisites for implementing the goals of Industry 5.0 in production practice. Circular economy allows to combine economic efficiency with the requirements of sustainable development and social responsibility. In the modern sense, it is not a separate environmental initiative, but a systemic economic basis of a new industrial paradigm. Thus, the integration of circular economy into the architecture of Industry 5.0 ensures the integrity of the approach to the

development of industry as a human-centric, sustainable and long-term social value-oriented system. Let us give the following justifications for the indispensability of circular economy in the architecture of Industry 5.0:

1. The classic understanding of the definition of Industry 5.0 is a concept of industrial development focused on human-centricity, sustainability and resilience, within which advanced digital and intelligent technologies are used not only to increase productivity, but also to ensure social responsibility, environmental safety and harmonious interaction between man, machine and environment. But let's consider it from a different perspective: Industry 5.0 is not about technology for the sake of efficiency, but about technology for the sake of man, society and the planet. Figure 1 presents the place of the circular economy in the opinion of the authors in Industry 5.0 technologies.

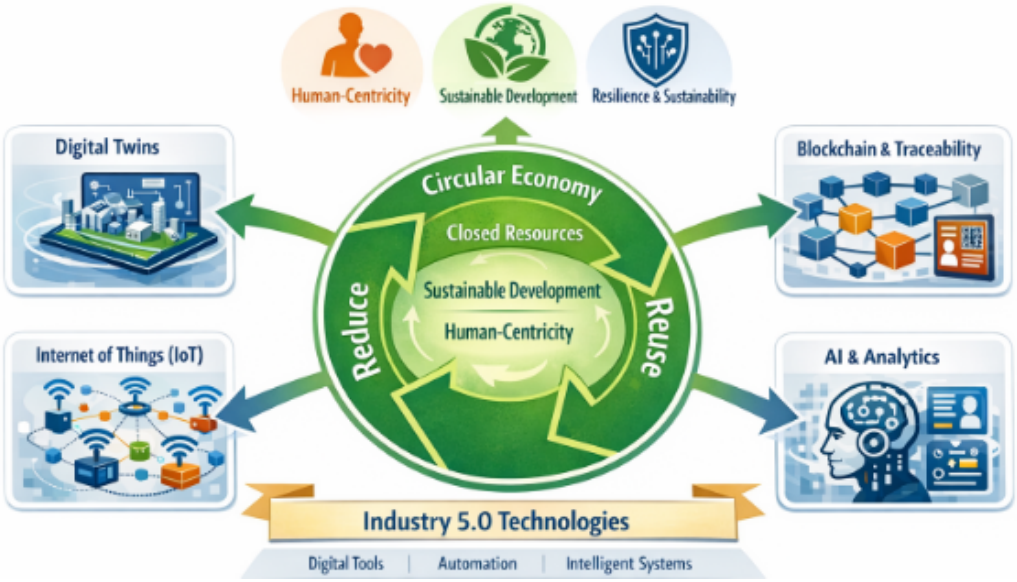

Figure 1. - The place of the circular economy in Industry 5.0 technologies.

The circular economy is an economic model that implements this principle at the level of material, energy and information flows. A comparison of the key points and differences between Industry 4.0 and Industry 5.0 from the perspective of the circular economy is presented in Table 1.

Table 1. - Comparison of key points and differences between Industry 4.0 and Industry 5.0 in terms of taking into account the circular economy

Industrial Revolutions	
Industry 4.0	Industry 5.0
Efficiency	Sustainability + humanity + responsibility
Maximizing productivity	Balance between economy, ecology and society
Linear model:take–make–waste	Circular model:reduce–reuse–repair–recycle

2. Human-centricity as a basic principle of Industry 5.0 involves focusing industrial development not only on economic efficiency, but primarily on human well-being, quality of life and social responsibility of production. In this context, the circular economy is a key mechanism for the practical implementation of a human-centric approach, since it is aimed at reducing the negative impact of production activities on public health by reducing emissions, waste and environmental pollution. At the same time, circular business models stimulate the development of new forms of employment, in particular in the areas of repair, restoration, remanufacturing and processing of products, which contributes to social inclusion and the creation of added value at the local level. In addition, reducing dependence on primary resources increases the economic security of countries and reduces the vulnerability of society to global resource crises. Thus, it is through the implementation of circular business models that the human-centricity of Industry 5.0 acquires practical meaning, transforming a declarative principle into a practical tool for balancing economic, social and environmental interests.

3. Sustainability and the ability to recover are defined as key goals of the Industry 5.0 paradigm, since modern industrial systems must function in conditions of resource constraints, environmental challenges and growing instability of global markets. In this context, the circular economy provides a practical implementation of the principle of sustainability through the formation of closed material and energy cycles in production.

Transforming waste into secondary resources reduces landfill volumes and the associated environmental impact, while also reducing the need for primary extraction of raw materials. Minimizing primary consumption of resources reduces the burden on natural ecosystems and increases the long-term resource security of industrial systems. Reducing the carbon footprint through the reuse of materials and energy contributes to achieving climate goals and reducing environmental risks. Thus, circularity is not an auxiliary element, but a fundamental mechanism for ensuring the sustainability and resilience of industry within the Industry 5.0 paradigm.

4. Digital technologies are a key instrumental component of the Industry 5.0 paradigm, enabling the practical implementation of the principles of the circular economy in industrial systems. Technologies such as digital twins, the Internet of Things, intelligent data analysis algorithms and traceability systems based on blockchain and digital product passports, form the information infrastructure required to manage closed economic cycles. These technologies enable tracking of materials and components throughout the entire product life cycle, ensuring transparency of resource flows and responsibility of supply chain participants. Based on the collected data, it is possible to optimize the reuse, recovery and remanufacturing of products, reducing the need for primary resources. Intelligent degradation prediction models allow determining the optimal moments for maintenance and repair, extending the service life of products and reducing waste. Real-time data-based management of secondary raw material flows increases the efficiency of its collection, sorting and processing. Thus, Industry 5.0 provides technological tools for the implementation of circular processes, while the circular economy defines the goals and directions of their application within the framework of a sustainable and human-centric model of industrial development.

Let us describe the formal relationship in the form of a logical model:

$$Industry\ 5.0 = Human-centric + Sustainable + Resilient + Digital \quad (1)$$

$$Circular\ Economy = Economic\ model, \text{ що реалізує } Sustainable + Resilient \text{ через замкнуті цикли ресурсів} \quad (2)$$

Combining expressions 1 and 2 allows us to derive the following formal model:

$$Industry5.0 = Technology + CircularEconomy + HumanValues \quad (3)$$

Without a circular economy, Industry 5.0 simply becomes a “more ethical Industry 4.0”, not a new paradigm. Here is an example of a practical combination of circular economy and Industry 5.0 technologies, which is shown in Table 2.

Table 2. - Example of a practical combination of circular economy and Industry 5.0 technologies

Industry 5.0 component	How it supports circularity
Digital twin	Simulates wear and tear and repair instead of replacement
IoT-sensors	Controls material degradation
AI / ML	Optimize reuse
Robot manipulators	Automate sorting and remanufacturing
HRC (Human-Robot Collaboration)	Safe teamwork in repair and dismantling

Circular economy is the economic implementation of the principles of Industry 5.0, ensuring the closure of material and energy flows, reducing environmental impact and increasing social responsibility of production. In turn, Industry 5.0 provides digital, robotic and intelligent tools for the effective implementation of circular business models, creating synergy between technological progress, sustainable development and human-centricity.

3. CONCLUSION

The study showed that the circular economy is not an auxiliary element, but the economic basis of the Industry 5.0 paradigm, ensuring the coordination of technological development with the requirements of sustainability, resilience and human-centricity. The integration of circular principles allows reducing resource dependence, environmental load and social risks of modern production. Digital technologies of Industry 5.0 create an instrumental basis for managing closed material and energy cycles in real time. Thus, a holistic socio-technical and economic system is formed that combines economic efficiency with responsibility towards society and the environment. The results obtained confirm the feasibility of considering the circular economy as the foundation of a new industrial paradigm, and not as a separate environmental initiative. This opens up prospects for further

research in the direction of modeling, optimization and scaling of circular processes within the framework of Industry 5.0.

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