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Development of robotic circular reproduction in ensuring sustainable economic growth

Abstract. To confront global challenges in the field of environmental security, humanity needs reproduction chains of a new type that correspond to the models of the green economy and the principles of sustainable development. The most relevant concept that meets these conditions is a circular economy. A new round of industrial development provides additional opportunities to introduce principles of circular reproduction. The proliferation of robots and the introduction of artificial intelligence systems will facilitate the implementation of circular innovations. The purpose of the paper is a study of current trends in the transformation of global value chains based on the symbiosis of virtual and physical production systems which form new operating models and contribute to sustainable economic growth. The research methodology includes general scientific methods of cognition, systemic and situational approaches, methods of structural and functional analysis, empirical generalization and comparison, as well as tabular and graphical methods of visualization of statistical and calculated data. The main results of the study are to gain new knowledge about the role of interaction between digital and physical spaces in ensuring the achievement of goals of sustainable development and the implementation of principles of circular reproduction. Studying robotic circular reproduction will increase the relevance of the concepts of a green economy and circular reproduction, which will promote effective implementation of the above concepts in the Russian Federation.
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Розвиток роботизованого циркулярного відтворення в забезпеченні сталого зростання економіки

Анотація. Для протидії глобальним викликам у сфері екологічної безпеки людству необхідні відтворювальні ланцюжки нового типу, що відповідають моделям «зеленої» економіки й принципам сталого розвитку. Найбільш актуальною концепцією, яка відповідає цим умовам, є циркулярна економіка. Новий виток індустріального розвитку забезпечує додаткові можливості для впровадження принципів циркулярного відтворення. Поширення роботів і впровадження систем штучного інтелекту будуть сприяти реалізації інновацій циркулярного характеру.

Метою статті є дослідження сучасних тенденцій в області перетворення глобальних ланцюжків створення цінності на основі симбіозу віртуальних і фізичних систем виробництва, який формує нові операційні моделі та сприяє сталому економічному зростанню.

Методологія дослідження включає в себе загальнонаукові методи пізнання, системний, ситуаційний підходи, методи структурно-функціонального аналізу, емпіричного узагальнення й порівняння, а також табличні й графічні прийоми візуалізації статистичних і розрахункових даних.

Основні результати дослідження полягають в отриманні нових знань про роль взаємодії цифрового та фізичного просторів у забезпеченні досягнення цілей сталого розвитку й реалізації принципів циркулярного відтворення. Вивчення досвіду застосування технологій роботизованого циркулярного відтворення дозволить підвищити актуальність концепцій «зеленої» економіки й циркуляційного відтворення та адаптувати їх до ефективного впровадження на території Російської Федерації.

Ключові слова: циркулярна економіка; індустрія 4.0; цифрова економіка; цифрові технології; роботизація; штучний інтелект; циркулярні бізнес-моделі; сталий розвиток.

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Развитие роботизированного циркулярного воспроизводства в обеспечении устойчивого роста экономики

Аннотация. Для противостояния глобальным вызовам в сфере экологической безопасности человечеству необходимы воспроизводственные цепочки нового типа, соответствующие моделям «зеленой» экономики и принципам устойчивого развития. Наиболее актуальной концепцией, отвечающей этим условиям, является циркулярная экономика. Новый виток индустриального развития обеспечивает дополнительные возможности для внедрения принципов циркулярного воспроизводства. Распространение роботов и внедрение систем искусственного интеллекта будут способствовать реализации инноваций циркулярного характера.

Целью статьи является исследование современных тенденций в области преобразования глобальных цепочек создания ценности на основе симбиоза виртуальных и физических систем производства, формирующего новые операционные модели и способствующего устойчивому экономическому росту.

Методология исследования включает в себя общенаучные методы познания, системный и ситуационный подходы, методы структурно-функционального анализа, эмпирического обобщения, сравнения, а также табличные и графические приемы визуализации статистических и расчетных данных.

Основные результаты исследования состоят в получении новых знаний о роли гибкого взаимодействия цифрового и физического пространств в обеспечении достижения целей устойчивого развития и реализации принципов циркулярного воспроизводства. Изучение опыта применения технологий роботизированного циркулярного воспроизводства позволит повысить актуальность концепций «зеленой» экономики и циркуляционного воспроизводства и адаптировать их к эффективному внедрению на территории Российской Федерации.

Ключевые слова: циркулярная экономика; индустрия 4.0; цифровая экономика; цифровые технологии; роботизация; искусственный интеллект; циркулярные бизнес модели; устойчивое развитие.

1. Introduction

In order to face up to the global challenges in the field of environmental safety, humanity needs a new type of reproduction chains that correspond to the models of the green economy and the principles of sustainable development. The most relevant concept that meets these conditions is a circular economy. Its key feature lies in the multiway use of products based on the secondary use of wastes or its complete disposal.

A new round of industrial development characterized by digital transformation and the fourth industrial revolution provides additional opportunities to introduce the principles of a circular economy. A special place in this process is occupied by the spread of robots and the introduction of artificial intelligence systems that contribute to the implementation of circular innovations. Robotic production chains will make it possible to achieve the stated goals to maximum effect. During the fourth industrial revolution, in addition to automatic and adaptive industrial robots, the third-generation robots with artificial intelligence are being introduced. They are fully integrated into the global Internet of Things, which helps to strengthen control over production processes in terms of minimizing the consumption of primary raw materials and increasing the volume of processed resources. This approach will significantly decrease the generation of wastes which are eventually sent to landfills and will reduce the area of disposal sites and unauthorized landfills. Ideally, the consequence of using robots with artificial intelligence and increased digitalization of reproduction processes will be the closure of the production cycle and absolutely non-waste production, contributing to the achievement of sustainable development.

2. Brief Literature Review

At present, a large number of works by both domestic and foreign researchers are devoted to the development of conceptual foundations of robotic circular reproduction. Features of reproduction processes have been considered by O. A. Lamovtseva (2010). The relationship between the implementation of the circular economy principles and the achievement of sustainable development goals has been revealed in the works by N. V. Pakhomova, K. K. Rikhter, M. A. Vetrova and D. Gerasimenko (2017). The importance of transition to a circular economy has been discussed by V. D. Alexandrova (2017). The significance of digital transformation of the economy to introduce principles of circular production in terms of production processes based on artificial intelligence has been revealed by V. V. Mylnik and A.V. Mylnik (2014). The evolution of the theory of circular reproduction and closed supply chain has been reflected in the works by J. Guide and L. Wassenhove (2009). The world experience in implementing the principles of circular reproduction has been considered in the works by foreign authors such as F. Preston and J. Lehne (2017), G. Hervey (2018), D. Benton and J. Hazel (2019), R. Sarc et al. (2019) as well as, J. O. Strandhagen et al. (2019).

Meanwhile, the issues of implementing the principles of robotic circular reproduction in ensuring the achievement of sustainable development have not been fully covered by either the researchers listed above or any other authors and, therefore, need additional scientific research.

3. Purpose

The purpose of the paper is to study current trends in the transformation of global value chains based on the symbiosis of virtual and physical production systems, which forms new operational models thus contributing to sustainable economic growth.

4. Methodology

To achieve the goal of the present study, general scientific methods of cognition, systemic and situational approaches, methods of structural and functional analysis, empirical generalization and comparison, as well as tabular and graphical methods of visualization of statistical data have been used.

5. Results

Interest in the implementation of circular business models is related to the deteriorating environmental situation, as well as to the idea of abandoning the linear economy based on output growth with unlimited use of natural resources. (Matviychuk-Soskina et al., 2019). The active use of the linear model has led to large-scale environmental problems, including the depletion of natural resources, emission of pollutants, greenhouse gases, growth of refuse and wastes, as well as to inefficient management of them. In this connection, the transformation of the national economic system in terms of increasing its sustainability, achieving climate goals and preserving natural resources is a high-priority task in making management decisions (Kolmykova, 2019).

The implementation of principles of circular reproduction will provide for the value of products, materials and resources to be maintained for as long as possible, returning those to the manufacturing cycle at the end of their use and minimizing generation of wastes. These principles should be implemented from the very beginning of the product life cycle, as its mental design and new production processes can help save resources, avoid inefficient waste management, and create new business opportunities.

The ratio and structure of the advantages and possible risks related to a circular economy are different for each specific territory, which makes it necessary to differentiate the ways of its introduction in countries and regions with different levels of development. Moreover, the specific features of socio-economic priorities and the responsibility of social environmental have a significant impact on these processes. Countries with a robust economy, advanced technologies and production practices have a greater potential for the introduction a circular economy. However, it is here that there is an increased risk of the nominal use of circular models in order to gain additional access to markets and guarantee the preservation of countries' positions. Developing countries with a lower standard of living are able to apply the principles of circular reproduction as reasonably as possible. For example, the presence of circular models in the manufacturing activity of developing countries is mostly associated with the sorting and reuse of waste, which makes it possible to obtain the so-called «growth points» for the sustainable development of the territory, contributing to the promotion of various forms of innovation by the business community, government and other stakeholders (House, 2017).

In the associations of countries, in particular in the European Union, each country also has its own peculiarities of implementing the principles of robotic circular reproduction. For example, in Germany, which has a strong industrial economy, the basis of circular reproduction is formed through material flow and the availability of materials; in the Netherlands - through innovations in materials and business models (Sachek, 2018). Finland is the first country to introduce a national roadmap for the transition to the circular economy (Finnish road map to a circular economy 2016-2025). It is natural that it is large European countries, such as the United Kingdom, Germany and France that take the leading positions in assessing the development of robotic circular reproduction, having a higher volume of investments, patents and jobs in the circular sectors of the economy. For example, it is Germany that ranks first in the number of patents related to the circular economy, being significantly ahead of France, which is in the second position (1,260 patents against 542). Also, Germany and the United Kingdom are leaders in circular investments, in many respects surpassing other European countries (Shershunovich, 2018).

A continued trend of large amounts of waste generation in Western and Northern European countries affects the decline of positions of countries such as Sweden, the Netherlands and Denmark in the circular economy ranking. Even a sufficiently high level of the development of waste recycling industry and financing of environmental innovations cannot change the situation for the better. The largest amount of municipal waste per capita per year is generated in Denmark - 777 kg/person; the smallest in Romania - 261 kg/person. The Netherlands is the leader in the level of food waste generation (541 kg/person). The lowest value is recorded in Slovenia (72 kg/person). The countries of Central and Eastern Europe show the lowest level of consume and food wastes generation (Hervey, 2018).

The effective application of principles of circular reproduction is characteristic of Asian countries. For example, in Japan, the law on promoting the efficient use of resources was adopted in 2000 (Ministry of Economy, Trade and Industry of Japan, 2000). Currently, Japan's recycling rates speak for themselves: the country recycles 98% of all metals. Based on the disposal laws, the vast majority of electric and electronic products are recycled with the recovery of up to 90% of the materials suitable for further use. Many of them return to the production of similar types of products, which meets the principles of circular reproduction. In the context of the industrial ecology program, the circular economy in China is beginning to develop (Benton & Hazel, 2015). Today, China has a well-formed legislative framework for the circular economy, and the concepts of environmental design and expanded responsibility of manufacturers are widely used, which together indicates significant progress in solving this issue (UNEP, 2016).

The process of social reproduction integrates individual reproduction processes at the level of specific companies and industries. The introduction of the circular reproduction principles at this level is based on the implementation of innovative business models. Such models promote the use of fewer materials and resources, extending life of existing products, and completing the product life cycle by recycling and benefiting from the remaining value of products and materials.

In particular, circular business models that ensure sustainable economic growth include:

1. Circular deliveries: limited resources are replaced with fully renewable sources. In the world practice, car manufacturing and the energy industry are the leaders in this sphere. The model is based on labour-intensive and long-term scientific research and development aimed at finding sources of providing production processes with fully recyclable or biodegradable resources. In Russian regions, circular deliveries, in addition to the car and energy industries, can be applied in agriculture, food production and production of packaging materials.
2. Resources recovery: use of technology innovations for recovery and reuse of resources. Its implementation is most relevant at enterprises that produce large volumes of by-products and have the ability to effectively recover and recycle waste.
3. Platforms for the exchange and shared use. The model is based on the sharing or exchange of assets or products. It has an increased potential for implementation within the framework of business partnerships, allows participants to interact in order to distribute fixed costs and generate additional profits from joint operation, which increases the overall efficiency of business as a whole.
4. Extension of the product life cycle: a model that allows companies to extend the life cycle of their products through repairs, upgrades, renovations or refurbishments. The remanufacturing industry can be formed within the Russian car industry, production of large appliances, the aerospace industry and the military industrial sector which have the potential capacity to restore products based on primary production.
5. Product as a service: a model in which customers use products through a «rent» on the pay-as-you-go basis. It serves as an alternative to buying a product through a rental or a leasing agreement. If implemented, the manufacturer, who retains ownership of all materials and equipment, has an incentive to create a product with a long life cycle, optimized for reuse or disposal of its individual parts at the end of its service life. This business model can be applied in the segment of leasing of large-tonnage and small-tonnage machines or agricultural machinery, since instead of buying an expensive product, it is more profitable for the consumer to purchase a package of services (Pakhomova et al., 2017).

It should be noted that new technologies inherent in Industry 4.0 and the digital economy are essential to the implementation of these business models. These include platform solutions, Big Data, the Internet of Things, robots and artificial intelligence systems. Robotics technologies have already been introduced in many areas of human activity. Robots are actively used to meet people's household and social needs, to automate production processes, to provide prompt and safe assistance during emergencies, etc. Most often, the introduction of robotics in the reproduction process is related to its optimization, which makes it possible to reduce costs and duration of the production cycle, improve product quality, eliminate the factor of human error, and more (Kolmykova & Merzlyakova, 2019).

According to the definition of the International Federation of Robotics, a robot is a working mechanism that is programmed along several axes with some degree of autonomy and is able to move within a certain environment, performing assigned tasks (IFR World Robotics). Traditionally, robotics is divided into the industry robotics designed to perform industrial automation tasks, and the service robotics that fulfils useful functions for people and equipment.

The technological vector set by the fourth industrial revolution lies in the transition to fully automated production with the introduction of digital technologies and self-organizing cyber-physical systems. Autonomous industrial robots, which are a cost-effective alternative to human labour, are an important part of them and are used in an ever-expanding list of industries. Robots are most actively used in the car industry (about 33% of the total number of installed robotic systems), electrical engineering and electronics (32%), metalworking and mechanical engineering (12%), plastics and chemical products (6%), food and beverages (2%) (ABI Research, 2020).

At the end of 2019, there are 2.7 million robots in the world, which is 12% higher than in 2018. It is expected that in the period from 2020 to 2022, about 2 million units of industrial robots will be installed at factories around the world. New technological trends and market development will allow companies that are actively introducing robots to respond quickly to changing requirements. The dynamics of sales of industrial robots worldwide is positive (Figure 1). Sales growth in 2019 was 15%, as compared to 10% in 2018. IFR World Robotics estimates that the overall industrial robot market has a favourable outlook with expected growth by 14% and 13% in 2020 and 2021, respectively. This dynamics is also due to the global economic crisis associated with the COVID-19 pandemic that will stimulate digitalization and create additional opportunities for the growth of robotics around the world (IFR World Robotics, 2020).

The geographical aspect of the development of the industry robotics market is shown in Figure 2. The Asian market is still the largest and fastest growing robotics market in the world. Its growth in 2018 was about 18%, which is primarily due to the rapid development of the Chinese economy. The North and South American market is the next largest. The European market

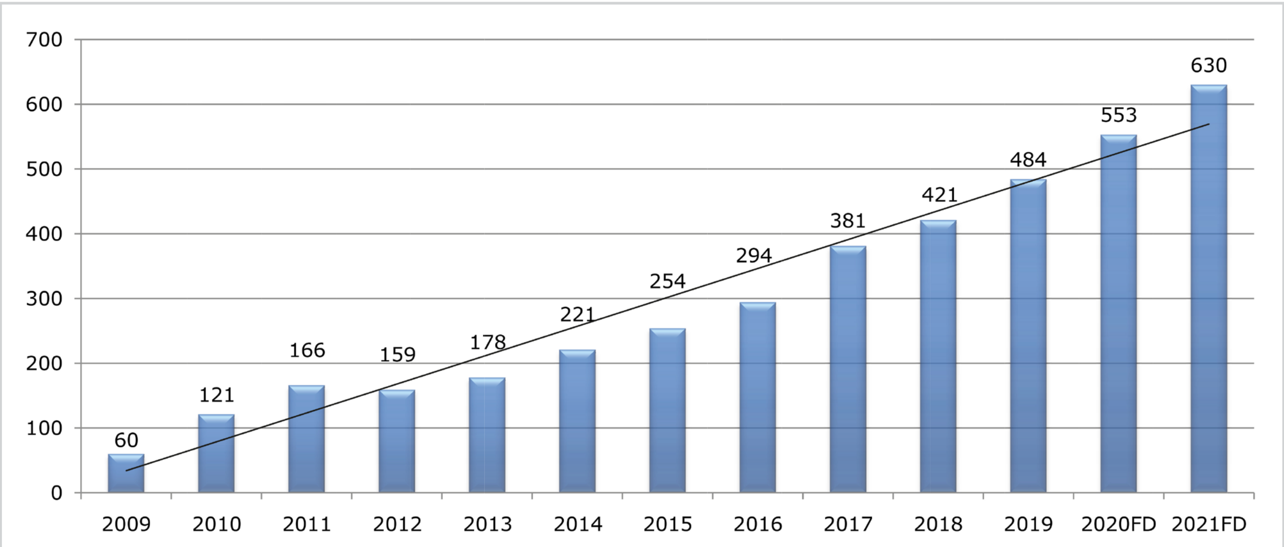

Figure 1:
Dynamics of sales of industrial robots in the world in 2009-2021 with forecast data (FD), thousand units
Source: IFR World Robotics (2020)

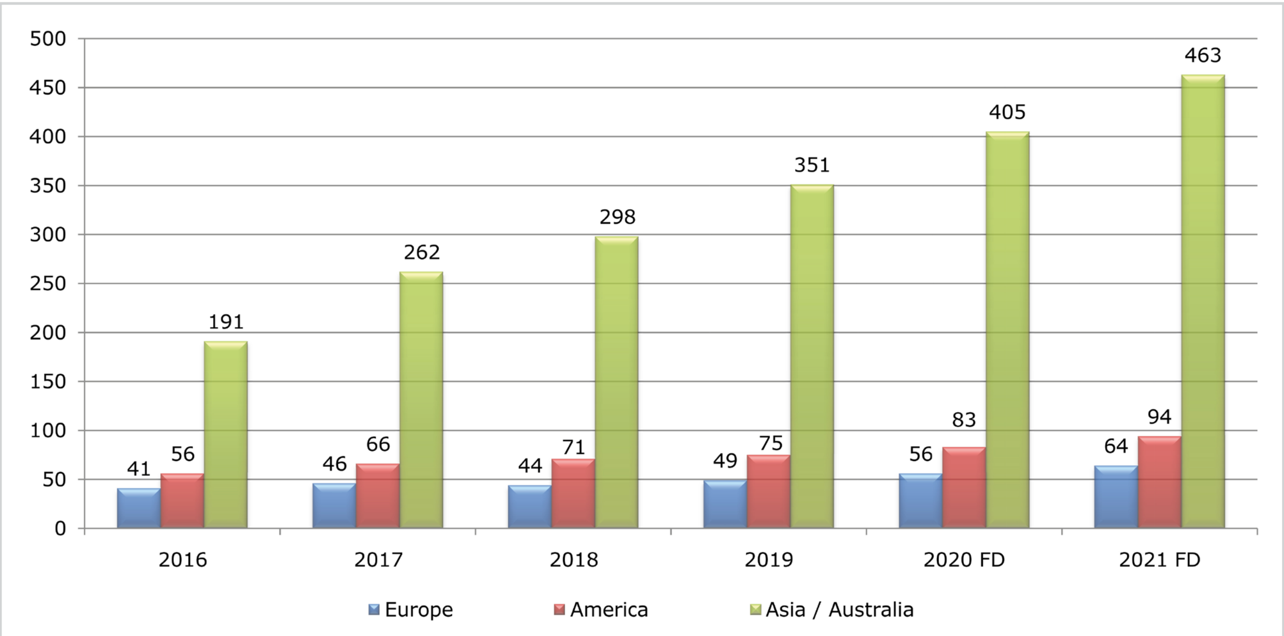

Figure 2:
Dynamics of sales of industrial robots in enlarged regions in 2016-2021 with regard to forecast data (FD), thousand units
Source: IFR World Robotics (2020)

occupies a slightly smaller volume. However, it surpasses the US market in terms of growth rates. In 2019, the sales gain of industrial robots in Europe exceeded 11%, while in America the figure is less than 6%. It should be noted that more than 70% of global sales are accounted for by 5 countries, namely China, Japan, the Republic of Korea, the US and Germany. At the same time, China is a confident market leader. At present, every third industrial robot in the world is sold in China. In addition to that, the country occupies a leading position in the number of installed and operating robots, and also demonstrates a high density of robotics (97 robots per 10,000 engaged in industries) (IFR World Robotics, 2020).

The service sector robotics covers a wider range of applications, most of which have unique designs and varying degrees of automation. Unlike the industrial robots, the service sector robotics is more diverse. According to IFR World Robotics estimates, at the end of 2019, about 890 companies were producing service robots or were engaged in commercial research in this field. Sales of professional service robots are growing. In 2019, the professional service robots market grew by 32% (from USD 8.5 to USD 11.2 billion). The COVID-19 pandemic has not had a negative impact on the markets of most types of service robots. On the contrary, it has increased the market for robotic disinfectants and created additional demand for robotic logistics solutions in warehouses, factories and home delivery. The turnover of medical robotics in 2019 increased by 28%, which is 47% of the total turnover of professional service robots. This was mainly related to robotic surgical systems which are the most expensive type of service robots. Robotic solutions are widely used in logistics, showing high growth of potential. Logistics robots make up 43% of the total number of professional service robots. In 2019, the number of robots sold increased by 42%, and the turnover - by 110%. Sales of professional and personal service robots will continue to grow, according to an IFR World Robotics forecast. If at the end of 2019 there were 173 thousand units, then by 2023, the number of professional service robots will increase to 537 thousand units. Similar trends are expected in the sector of personal service robots. For example, the number of robotic devices for solving home and household tasks in 2019-2023 will increase from 18.6 to 48.6 million units, and service robots in the entertainment sector from 4.6 to 6.7 million units (IFR World Robotics, 2020).

Thus, the scale and speed of robotics spread is great, as well as the possibilities of its application to achieve the main goal of the circular economy which lies in the most efficient and comprehensive use of resources. Digital technologies play an essential role and are already actively used to improve solutions in the field of circular reproduction and overcome existing problems in this area (Bressanelli et al., 2018) For example, the circular business model mentioned above is a promising one. It is based on the sharing and leasing of products instead of selling and is implemented with the help of digital technologies (platform solutions, professional service robots, etc.) (Bocken et al., 2016). Moreover, digital technologies can be integrated into existing business models to increase the visual aspects and descriptiveness of production results using robotic sensors that provide information about assets, their location, condition and availability (Antikainen et al., 2018). As a result, manufacturers will be able to track, analyze, control and optimize product characteristics throughout the entire service life, collecting information about the use of materials and components, which will increase the efficiency of reverse logistics and give goods, their materials and components a second life (Salmela & Happonen, 2009).

Artificial intelligence and robotic solutions provide automatic and remote monitoring of production process efficiency. The technologies improve the mass analysis of information about the processes of production, use and disposal of products. Furthermore, the introduction of digital technologies reduces waste, extends the life of products and minimizes transaction costs, which increases the efficiency of production processes in general and accelerates the formation of circular business models (Ghoreishi & Happonen, 2020). The convergence of circular economy business models and Industry 4.0 technologies increases the level of sustainability, giving business a new perspective on production and consumption and providing additional incentives for companies.

6. Conclusions

Digital economy and Industry 4.0 technologies are among the key solutions in accelerating the transition to the circular reproduction and increasing the sustainability of economic growth. At the same time, the robotic circular reproduction is a new, promising and rapidly developing area that attracts a lot of attention from businesses, governments and researchers. The problems of circular ecosystems, searching for the place and role of robotics and artificial intelligence at different stages of circular reproduction with regard to the industry specifics should be covered in future scientific research. In addition to that, a clear plan to introduce the robotic circular production principles is needed, including key events, their deadlines, responsible performers and coordinators.

Taking into account the world experience in the application of robotic circular reproduction technology, we can already identify three key areas in terms of the introduction of these principles on the territory of the Russian Federation:

- improving processes of secondary use of products, component restoring and recycling of materials based on the introduction of robots and artificial intelligence systems that close the production cycle and perfect the infrastructure of reverse logistics;
- expansion of innovative circular business models with the use of robotics and artificial intelligence in terms of collecting and managing information in real time, taking into account historical data about users and products;
- designing and developing products, components and materials that comply with the principles of a circular economy.

The consequences of such transformations determine tangible benefits for society and businesses. In particular, they consist in optimizing waste management; reducing air, soil and water pollution; introducing more innovative and efficient ways of production and consumption; protecting businesses from resource shortages, volatile prices, etc. Thus, the introduction and further development of robotic circular reproduction will make the national economy more stable and competitive.

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