KAPITEL 10 / *CHAPTER 10* [10]
THE IMPACT OF NEW TECHNOLOGIES ON ACHIEVING SUSTAINABLE INDUSTRIAL DEVELOPMENT

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Introduction

The consequences of climate change — in particular rising temperatures and sea levels, extreme weather events, as well as the degradation of water resources and raw materials — pose serious challenges for the development of the industrial sector. This sector remains one of the main sources of greenhouse gas emissions and is a significant consumer of non-renewable resources (see Figure 1).

Consequence: Rising temperatures
Effect: leads to extreme weather conditions, which negatively impact energy supply, equipment cooling, and production processes.

Consequence: Extreme weather events
Effects: can damage infrastructure, disrupt supply chains, and lead to financial losses.

Consequences of climate change
For industrial enterprises, the critical consequences of climate change are precisely those that create additional challenges in their operations.

Consequence: Rising global sea levels
Effect: Threatens coastal industrial areas, ports, and logistics centers, potentially leading to production stoppages and increased adaptation costs.

Consequence: Degradation of water resources and raw materials
Effect: Shifts in climate zones and freshwater scarcity complicate production processes that depend on water supply and raw materials.

Figure 1. - Consequences of climate change posing serious challenges to the development of the industrial sector

Note:
The term "climate change" refers to long-term and significant changes in the average climate on Earth or in specific regions, occurring over decades or longer, and caused by human activities.
Source: compiled based on [2; 4]

Given the systemic impact of the outlined consequences, it becomes evident that purely environmental measures no longer meet current requirements or the scale of the threats. The author's earlier research has shown that many manufacturing enterprises—including LLC "Ariant", LLC "Polymya," PE "Kiptik", and AQUA Radiator— declare about the following "green" principles, or try to cut harmful emissions. However, they

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often lack clear plans or reporting systems to meet these goals. Also, some companies claim to use sustainable development principles. In practice, they focus on economic gains while neglecting environmental and social aspects [1].

Therefore, we emphasize that industrial enterprises need to transition to genuine sustainable development strategies, based on the implementation of innovative technologies capable of reducing environmental impact without compromising production efficiency or social responsibility.

10.1 Technological trends in sustainable development.

Research by non-governmental organizations, including the Global Compact Network Ukraine (the Ukrainian network of the world's largest community of responsible businesses, providing expertise in environmental, social, and corporate governance), the World Resources Institute (which conducts research aimed at improving people's lives, protecting nature, and combating climate change), and the International Energy Agency (which performs analyses and provides recommendations for the development of clean energy technologies), indicates that new technologies are currently a key tool for achieving sustainable development goals.

According to a World Resources Institute (WRI) study conducted in collaboration with other organizations or institutions (such as government agencies, universities, research centers, or other NGOs), among 1,000 industrial enterprises surveyed between 2021 and 2024, the main areas of transition toward sustainable development include:

- The use of energy-efficient technologies and renewable energy production technologies reduces dependence on fossil fuels.
- The implementation of Industry 4.0 technologies optimizes production processes and minimizes resource losses.
- The development of circular economy technologies, particularly those focused on recycling, material reuse, and the implementation of zero-waste production processes.
- The application of biotechnology and advanced materials production

technologies is capable of significantly reducing the harmful impact of industry on the environment.

More detailed results of the WRI study regarding the impact of new technologies on achieving sustainable industrial development in 2021–2024 are presented in Table 1.

Table 1 - Results of the WRI Study on the Impact of New Technologies on Achieving Sustainable Industrial Development, 2021–2024

Technologies applied for transition to sustainable development	Number of respondents applying technologies for achieving sustainable development (out of 1,000), units.*								Average monetary assessment of the triple sustainable development effect produced by the technologies per sample unit, million USD (Y)				XY relationship equation (Y=a+bX) **
	Simultaneous application of a single technology (X1)				Simultaneous use of multiple technologies (X2)								
	2021	2022	2023	2024	2021	2022	2023	2024	2021	2022	2023	2024	
Energy-efficient and renewable energy production (X1)	269	310	330	370	150	165	190	240	10,6	13,9	16,4	28,8	Y = -39.39 + 0.18X1
Industry 4.0 (X2)	160	220	309	330									Y = -3.9+ 0.083X2
Circular economy (X3)	100	160	206	264									Y = -2.02 + 0.11X3
Biotechnology and advanced materials production (X4)	85	120	170	284									Y = 2.4652 + 0.09X1

Note:
"1,000" refers to the sample size, i.e., the number of industrial enterprises on which the conclusions were based. For more detailed information regarding the sample, it is recommended to contact WRI or its partners directly, who can provide access to the relevant data or reports.
**Y — dependent variable, X — independent variable, b — regression coefficient, indicating how much Y changes when X changes by 1, a — intercept.

Source: Compiled from WRI data

The data indicate that, across the overall sample, the number of industrial enterprises actively applying various types of technologies for the transition to sustainable development has increased.

The most significant growth was observed among enterprises using energy-

efficient technologies, renewable energy production technologies (from 269 units in 2021 to 370 units in 2024), and Industry 4.0 technologies (from 160 units in 2021 to 330 units in 2024), reflecting their priority in ensuring the integration of economic, environmental, and social aspects of sustainable development.

The outlined priority is also confirmed by the impact of these technologies on the triple sustainable development effect (Y). For instance, an increase of one enterprise using energy-efficient technologies leads to an average increase in Y of 0,18 million UAH, while an increase of one enterprise using renewable energy production technologies results in an average increase in Y of 0.84 million UAH.

Significant growth was also observed in the number of enterprises using circular economy technologies (from 100 units in 2021 to 264 units in 2024) and biotechnology and advanced materials production technologies (from 85 units in 2021 to 284 units in 2024).

The outlined priority is also confirmed by the impact of these technologies on the triple sustainable development effect (Y). An increase of one enterprise using circular economy technologies leads to an average increase in Y of 0.107 million UAH, while an increase of one enterprise using biotechnology and advanced materials production technologies results in an average increase in Y of 0.09 million UAH.

Moreover, the data in Table 1 indicate that industrial enterprises are gradually moving toward the simultaneous use of multiple technologies, which aligns with the concept of integrated sustainable development — harmonizing economic, environmental, and social aspects. As a result, the effects of these technologies accumulate and reinforce each other, creating a greater triple sustainable development effect than the sum of its individual components [1; 5].

It should be noted that these outlined changes and dependencies regarding the implementation of new technologies in industrial enterprises contributed to an increase in the average monetary assessment of the triple sustainable development effect per sample unit — from USD 10.6 million in 2021 to USD 28.8 million in 2024.

The implementation of such technologies in Ukraine has a varied impact on the harmonization of economic, environmental, and social aspects of industrial

development.

10.2 The impact of new technologies on achieving sustainable development goals

According to the Center for Environmental Initiatives "Ecodia" (based on aggregated statistical data and evaluations of the effectiveness of various measures aimed at transitioning industrial enterprises to sustainable development), the implementation of energy-efficient technologies and renewable energy production technologies in industrial enterprises contributes to achieving sustainable development in the sector by reducing energy consumption by 15–25% and replacing the use of conventional fossil fuels by 10–20%, depending on the type of enterprise [3].

Energy-efficient technologies include equipment, systems, and technological processes that reduce energy consumption without changing production volumes. In particular:

- The introduction of high-efficiency motors in production cycles reduces energy consumption by 25%.
- Modernization of lighting systems – by 15%.
- Thermal insulation of production facilities – by 20%.
- Optimization of technological processes to reduce energy losses by 25%.

Renewable energy production technologies involve the use of equipment to generate energy from renewable natural resources, which helps reduce the consumption of fossil fuels.

For example, the use of solar panels and wind turbines can reduce up to 10% of traditional energy consumption; biogas plants and geothermal systems – up to 13%; small hydropower installations – up to 20%.

The example of LLC "Ariant" demonstrates that the assessment of the effects of implementing these measures can be carried out by comparing baseline and expected energy consumption after the measures are implemented, taking into account the substitution of fossil fuels. Although the Ecodia Center provides only approximate indicators of energy consumption reduction and fossil fuel replacement when

implementing energy-efficient technologies and renewable energy (RE) solutions, these figures are still quite useful for assessing the potential impact on the sector.

For example, if the baseline energy consumption of LLC "Ariant" in 2024 was 1,000,000 kWh per year, the effect of implementing individual measures is calculated sequentially, as each subsequent measure impacts the already reduced energy consumption:

- after the introduction of high-efficiency motors, consumption decreased from 1000000 to 750000 kWh;

- after lighting modernization – from 750000 to 637500 kWh;

- after thermal insulation of premises – from 637500 to 510000 kWh;

- after optimization of technological processes – from 510000 to 382500 kWh.

Thus, the total energy savings of the enterprise amount to 1000000 − 382500 = 617500 kWh.

Regarding the substitution of fossil fuels, if the planned share of renewable energy (RE) reaches 15% of total consumption, the amount of replaced energy will be 150000 kWh per year.

In practice, this calculation allows for determining, in monetary terms, energy savings, reduction of greenhouse gas emissions, as well as improvements in the environmental and economic sustainability of production [6].

According to analytical statistics from the Center for Environmental Initiatives "Ecodia", based on observations and case studies of Industry 4.0 technology implementation in domestic industrial enterprises, as of 2024, these technologies contribute to sustainable development by increasing operational efficiency through a positive gap of up to 30% between revenue generated and the cost of resources used.

Artificial Intelligence (AI) improves product quality and reduces downtime through:

- optimization of production process parameters (reducing defects by 5–10%);
- predictive maintenance of equipment (reducing unexpected stoppages by 10–20%);
- real-time quality control (reducing defects by 8–12%);
- optimization of production schedules (reducing downtime by 10–15%);

- supporting decision-making regarding repairs and upgrades (minimizing repair costs and stoppages).

The Internet of Things (IoT) allows for continuous real-time monitoring of production systems and automatic process adjustments, resulting in a 10–20% reduction in resource losses.

Automation and robotics in repetitive or precise tasks can significantly minimize material and energy losses. Here are some examples:

- Automated sorting lines can reduce waste by 15%.

- Automated packaging systems can lower material losses by 15% to 25%.

- Robots for painting and coating can decrease paint and energy losses by 10% to 15%.

- Robotic sorting and transport systems in food production can minimize product damage and raw material losses by up to 15%.

- Automated systems for precision cutting or processing of metal and plastic can reduce waste by 10% to 20%.

Industrial analytics and digital twins enable scenario testing without the actual consumption of resources. Some benefits include:

- Modeling energy consumption in production lines, leading to energy savings of 5–15%.

- Optimizing material and product placement in warehouses, which can reduce transportation time by 10–20%.

-Simulating equipment operation cycles to achieve a reduction in downtime of 10–15%.

- Conducting virtual tests of new technological processes, resulting in raw material savings of 10–20%.

- Simulating optimal equipment loading, which can increase productivity by 5–15% and reduce energy losses.

Thus, to quantitatively assess the effectiveness of Industry 4.0 technologies, it is necessary to compare baseline production process indicators with those projected or achieved after implementation. This calculation can be illustrated using the example of

LLC "Ariant," with a baseline defect volume of 100000 units of wooden construction components and carpentry products per year and equipment downtime of 2000 hours.

At the same time, the implementation of AI allows for a 10% reduction in defects and a 15% reduction in downtime: defects decreased from 100000 to 90000 units (savings of 10000 units); downtime decreased from 2000 to 1700 hours (savings of 300 hours).

Additionally, the application of IoT and automation has reduced material losses by 15% and energy consumption by 10%: material losses: if initial losses were 50 t/year, after implementing the technologies they decreased to 42.5 t (savings of 7.5 t); energy consumption: if initial consumption was 1000000 kWh, after implementing the technologies it decreased to 900000 kWh (savings of 100000 kWh).

The overall effect illustrates that such comparisons provide quantitative data on the effectiveness of Industry 4.0 technology implementation and allow integration into a comprehensive enterprise sustainable development strategy, combining economic, environmental, and social benefits [6].

According to aggregated assessments and analytical statistics from the Center for Environmental Initiatives "Ecodia," as of 2024, circular economy technologies in Ukrainian industrial enterprises demonstrate significant potential to increase production resource efficiency by 20–25% [3]. This is achieved through the optimization of material flows and waste minimization.

The main directions for implementing circular economy principles are:

Recycling and reuse of waste, which reduces primary raw material costs by an average of 15% through the use of secondary resources (scrap metal, plastic, glass, paper, food waste);

Industrial symbiosis, which allows for a reduction of waste disposal and transportation costs by up to 25% by using by-products from one enterprise as resources for another (e.g., thermal energy, slags, or other industrial residues);

Reuse of water and energy, which reduces costs by 20% through the implementation of closed-loop water systems and the use of energy solutions based on secondary resources.

Therefore, to quantitatively assess the effectiveness of implemented circular economy technologies, it is necessary to compare baseline and projected indicators for costs of primary raw materials, resource consumption, and waste disposal before and after the implementation of these technologies.

At LLC "Ariant," the baseline costs for 2024 were as follows: primary raw materials with potential for recycling – 10000000 UAH; waste disposal – 2000000 UAH; water and energy resources – 5000000 UAH. In total, the resource-related costs amounted to 17000000 UAH.

The implementation of circular economy technologies has made it possible to achieve significant results in cost reduction. Through recycling and reusing waste, expenses decreased from 10000000 to 8500000 UAH, ensuring savings of 1500,000 UAH. The application of industrial symbiosis principles also demonstrated a positive effect: costs decreased from 2000000 to 1500000 UAH, resulting in savings of 500000 UAH. In addition, the reuse of water and energy reduced expenses from 5000000 to 4000000 UAH, bringing an additional saving of 1000000 UAH.

The total resource savings reduced overall expenses to 14,000,000 UAH. Thus, the implementation of these technologies allows LLC "Ariant" to reduce resource costs by approximately 17.6%.

Clearly, this approach allows for determining savings in raw materials, energy, and water, reductions in waste disposal costs, as well as the financial benefits from the reuse of materials and by-products [6].

According to aggregated analytical assessments by the Center for Environmental Initiatives "Ecodia," as of 2024, biotechnology and advanced materials production technologies implemented in domestic industrial enterprises demonstrate significant potential to increase production process efficiency by 23–27% [3].

Specifically, it's noted that biotechnology enables the use of living organisms, biological systems, or their components for industrial, medical, agricultural, and manufacturing purposes, including:

- production of biofuels (ethanol, biodiesel), biopolymers, and enzymes – fuel and raw material savings of 15–20%;

- replacement of traditional chemical reactions with more environmentally friendly bioprocesses or their optimization – savings of 10% in raw materials, energy, and auxiliary resources;

- reduction of harmful emissions and generation of hazardous waste – 5% savings in costs for air and water purification and waste disposal, as well as 10% reduction in costs for reagents or technological materials used to neutralize these emissions.

Advanced materials production technologies involve the development and industrial implementation of materials with enhanced properties for specific production tasks. On average, they provide 25–27% savings in raw materials, energy, water, waste disposal, and production resources, while increasing productivity, product durability, and resource efficiency of manufacturing processes.

To quantitatively assess the effectiveness of biotechnology and advanced materials production technologies, scientific studies typically use an integrated approach combining energy, resource, and economic indicators.

For example, at AQUA Radiator, the assessment of the effects of implementing these measures can be carried out by comparing baseline and projected levels of resource, energy, and material consumption before and after implementation.

To accurately calculate the effect, it is essential to consider the manufacturer's baseline indicators for 2024, which are as follows: raw material costs amount to 8000000 UAH, energy costs are 3000000 UAH, and water and waste disposal costs total 2000000 UAH. In total, the resource-related costs amount to 3000000 UAH.

The implementation of biotechnology has led to significant savings in various areas. Specifically, there has been a 15% reduction in raw material and fuel costs, totaling 1200000 UAH. Additionally, a 10% savings has been achieved in energy and auxiliary resources, amounting to 300000 UAH. Lastly, there has been a 10% decrease in costs for reagents and waste treatment, which corresponds to 200000 UAH. In total, the savings from using biotechnology are 1700000 UAH.

The implementation of advanced materials technology has allowed for significant

savings in resources and energy, totaling 25%. Specifically, the savings are as follows: raw material costs of 2000000 UAH, energy costs of 750000 UAH, and water and waste disposal costs of 500000 UAH. In total, the savings from using advanced materials amount to 3250000 UAH.

The total resource savings from the implementation of biotechnology and advanced materials technologies at LLC "Ariant" amount to 4950000 UAH, corresponding to approximately a 38% reduction in resource costs.

Thus, the implementation of these technologies ensures a significant increase in production process efficiency, reduction in resource expenses, mitigation of environmental impact, and improvement of product durability [6].

Summary and conclusions.

It has been demonstrated that new technologies integrate economic efficiency and environmental safety, making them strategically important for achieving sustainable development goals. They enable enterprises to produce more output with lower resource consumption and reduced environmental impact, ensuring long-term economic and ecological sustainability.

For instance, the use of energy-efficient technologies and renewable energy (RE) solutions helps reduce dependence on fossil fuels, decrease greenhouse gas emissions, and enhance the energy security of both enterprises and the country.

Industry 4.0 technologies contribute to the optimization of production processes, the minimization of material and energy losses, and increased productivity through real-time process monitoring and control.

The advancement of circular economy technologies reduces waste production, lowers disposal costs, and enhances resource efficiency for businesses.

Biotechnology and advanced materials production technologies help reduce environmental impact and decrease consumption of raw materials and energy.