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IMPLEMENTATION OF THE PRINCIPLES OF SUSTAINABLE DEVELOPMENT IN FOOD ENTERPRISES OF UKRAINE IN THE CONTEXT OF INDUSTRY 4.0

The paper discusses the problems and opportunities of implementing sustainable development in the context of Industry 4.0. It analyzes the difficulties associated with outdated technologies and the challenges of developing resilience strategies. The types of innovations in this field, their advantages, and disadvantages are described. A comparative analysis of the world and Ukrainian experience in implementing sustainable development in companies such as Danone, Nestlé, Unilever; Beyond Meat, Impossible Foods, BrewDog, LLC “Organic Milk”, LLC SP “Nibulon”, PJSC “Ternopil Dairy Plant» (Molokia), LLC “Ukrprodukt Group”, PJSC “Kyiv Confectionery Factory “Roshen”, PJSC “Chumak”, PJSC “Obolon is conducted. Strategies for successful implementation of sustainable development in the conditions of Industry 4.0 are proposed. The research results emphasize the need for an innovative approach to sustainable development and key principles for achieving success in this field.

Keywords: sustainable development, Industry 4.0, food enterprises, framework, implementation.

JEL classification: L60, O13, Q32, O14, O32, O33

Statement of the problem. Ukraine has significant potential in the food industry sector; however, due to increased demands for compliance with global standards and trends, businesses are faced with the challenge of developing strategies for implementing principles of sustainable development in the realms of ecological and social responsibility. Complications stemming from the use of outdated technologies, insufficient awareness of the importance of sustainable development, difficulties in devising an effective sustainability strategy due to lack of experience in implementing Industry 4.0 technologies and tools, lead companies to postpone this idea. This results in the loss of the opportunity to simultaneously ensure their businesses' higher competitiveness in the market, increase business process efficiency, and reduce the level of negative environmental and social impact. Therefore, developing a framework for implementing principles of sustainable development in food enterprises within the context of Industry 4.0 is a relevant issue for investigation.

Analysis of recent research and publications. Within the conducted research, the works of Ukrainian researchers such as Yu.M. Seredyuk, O.S. Khrinyuk [1], M.V. Nasteka [2], I. Migus [3], E. Dzhafarova, M. Karpenko [4] were examined. They addressed issues of implementing sustainable development principles, principles of implementation, and synergy development with Industry 4.0 technologies and tools. Additionally, the works of foreign scholars and specialists were considered and analyzed: Ellen MacArthur [5], Stefan Schmidt [6], Janine Benyus [7], Alan Savory [8], Michael Porter [9], Howard Bowen [10], Michael Braungart, William McDonough [11], John Elkington [12], Paul Hawken, Amory Lovins, Hunter Lovins [13], R. Edward Freeman [14], who presented innovative approaches and models for achieving sustainability in various aspects of economic activity and social life. The analysis of recent research and publications allowed identifying the main

challenges, shortcomings, advantages of each type of innovation, technology, and model of sustainable development, which became the basis for developing a framework for implementing principles of sustainable development in the context of Industry 4.0.

Objectives of the article. Developing a framework for implementing principles of sustainable development in Ukrainian food enterprises under the influence of Industry 4.0 trends and requirements.

Summary of the main research material. Global challenges are reshaping the business landscape. Ukrainian food enterprises are confronted with the necessity to adapt to new key trends of Industry 4.0, which entail deep digitization of production and management processes, integration of environmental, social, and economic standards into strategic plans. The digital transformation of food enterprises opens up new opportunities for implementing sustainable practices through the use of automated systems, which will optimize production processes and reduce resource and energy costs. The application of monitoring and analytics systems of big data will contribute to more accurate demand forecasting, waste reduction, and supply chain optimization. Therefore, the use of Industry 4.0 technologies and tools is necessary not only for increasing productivity, opening new markets, and business opportunities, but also for enhancing the environmental efficiency and social responsibility of food enterprises.

Despite the significant potential of this direction, implementing principles and technologies of sustainable development in the conditions of Industry 4.0 faces high costs of digital technologies, the need for personnel qualification improvement, development of effective mechanisms for state support and business stimulation. However, strategic planning and investments in innovative technologies can help overcome these barriers, paving the way for sustainable development of the food industry in Ukraine.

Let's consider the main types of innovative technologies in the field of sustainable development in accordance with Industry 4.0 (Figure 1).

As evident from the data in Figure 1, the aforementioned innovative technologies in the context of Industry 4.0 hold significant potential for supporting sustainable development through the integration of advanced technologies aimed at efficiency and minimizing environmental impact. Environmental innovations such as intelligent monitoring systems and energy-efficient technologies will help reduce

pollution levels and improve natural resource management. Digital innovations optimize resource usage through the application of intelligent systems for water supply, lighting, and agricultural monitoring systems. Social innovations will help engage the public in addressing environmental issues, while economic innovations will contribute to the creation of sustainable business models.

Let's consider the advantages of applying sustainable development technologies in the context of Industry 4.0 (Figure 2).

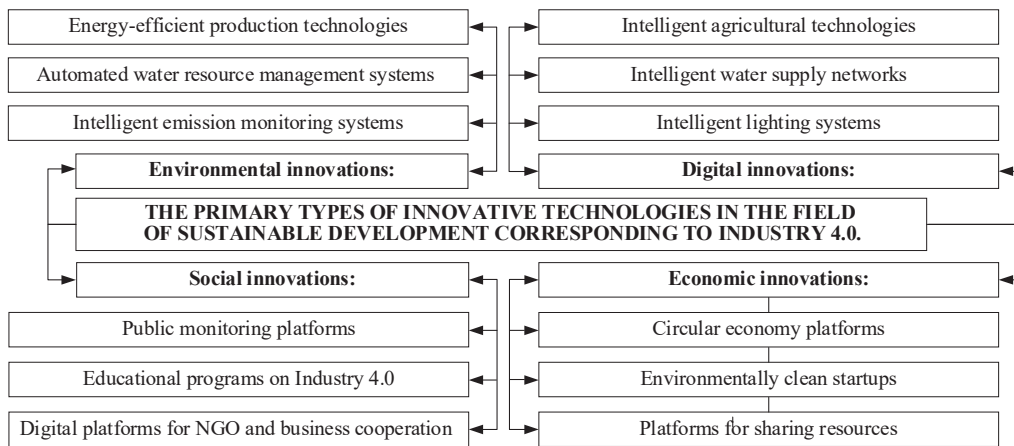


Figure 1 – The primary types of innovative technologies in the field of sustainable development corresponding to Industry 4.0

Source: formed on the basis of [15]

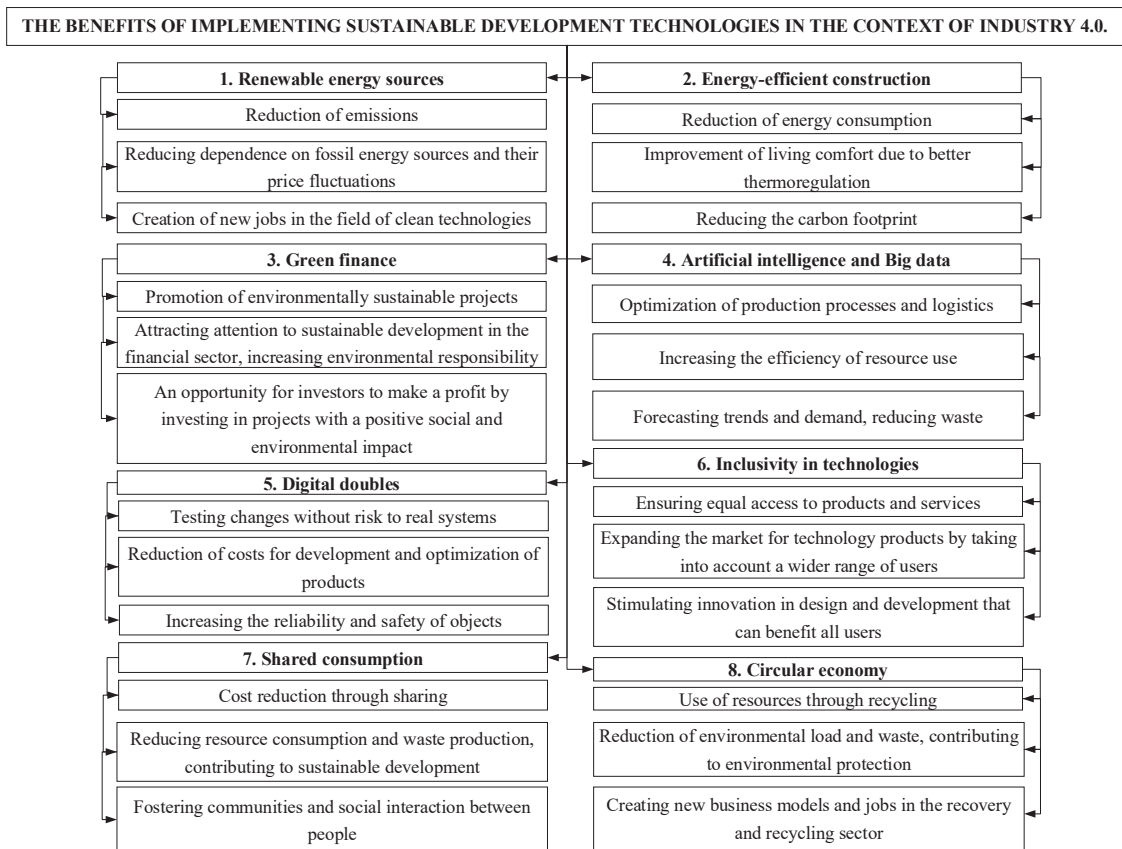


Figure 2 – The benefits of implementing sustainable development technologies in the context of Industry 4.0

Source: formed on the basis of [1–4; 15]

Based on the data from Figure 2, it can be concluded that the application of sustainable development technologies in the context of Industry 4.0 will contribute to: reducing carbon dioxide emissions and combating global warming; decreasing dependence on fossil fuel sources; improving energy efficiency and social comfort; optimizing production processes; creating new jobs and enhancing overall economic efficiency. Technological inclusivity and circular economy will open avenues for market expansion, stimulate innovation, promote environmental conservation by reducing ecological burdens at the state level. The engagement of green finance underscores the importance of investing in sustainable projects, contributing to global efforts for sustainable development. Thus, the identified benefits of applying innovations in the field of sustainable development form a multidisciplinary approach to addressing environmental, economic, and social challenges, laying the groundwork for a future where technologies serve not only human needs but also the preservation of the natural environment.

Let's consider the drawbacks of applying sustainable development technologies in the context of Industry 4.0 (Figure 2).

As evident from the data in Figure 3, it can be concluded that the high cost of implementing the aforementioned technologies depends on external conditions, the need for specialized knowledge, materials, complexity of technology implementation, logistics, and interaction with end-users. To address/minimize the drawbacks of applying

sustainable development technologies, the following recommendations can be highlighted:

1. For the effective implementation of renewable energy sources, the development and provision of financial instruments/subsidies to reduce initial costs are necessary. Additional integration with other energy sources and the development of storage technologies can mitigate dependence on weather conditions.

2. To implement energy-efficient building technologies, it is important to balance costs, overall design projects, and integrate innovative materials and technologies that can reduce operational costs over time and improve living comfort.

3. To implement the "Green Finance" project, clear criteria and standards for assessing the environmental efficiency of investments need to be developed to avoid risks of dubious investment spending and ensure access to funding from stakeholders.

4. For the implementation of artificial intelligence and big data technologies, clear data protection policies, confidentiality, incentives for investment in education and training of professionals capable of working with cutting-edge technologies are necessary.

5. The implementation of digital twin technologies requires not only significant initial investments but also continuous software updates to improve the accuracy of production process modeling, which requires a meticulous approach to data collection and analysis.

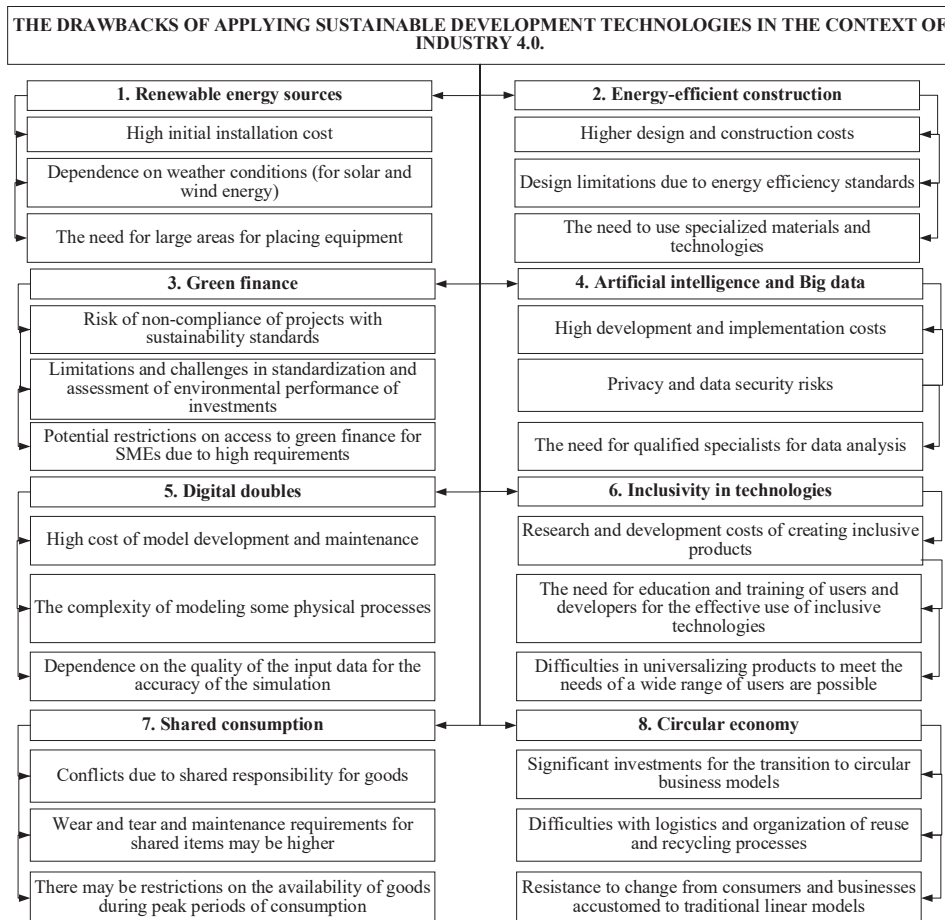


Figure 3 – The drawbacks of applying sustainable development technologies in the context of Industry 4.0

Source: formed on the basis of [5–14]

6. Inclusive technology implementation should address not only technical challenges but also reduce social barriers by offering solutions that consider diverse end-user needs.

7. Implementing principles of shared consumption requires the development of a culture of trust, responsibility, the development of effective management systems, and servicing of jointly used goods/services.

8. Implementing principles of circular economy requires a rethink of production and consumption processes, development of infrastructure for collection, processing, and reuse of materials.

Let’s consider modern models of sustainable development in the context of Industry 4.0 (Figure 4).

According to the data in Figure 4, innovative approaches to achieving sustainability in various aspects of economic activity and social life include the following models of sustainable development: Circular Economy (CE) [5], Eco-Efficiency [6], Biomimicry [7], Holistic Management in Agriculture [8], Sustainable Supply Chain (SSC) [9], Corporate Social Responsibility (CSR) [10], Cradle to Cradle (C2C) [11], Triple Bottom Line (TBL) [12], Natural Capitalism (NC) [13], and Stakeholder Management [14]. Each

of these models contributes uniquely to the development of strategies for reducing negative environmental impact, optimizing resource utilization, ensuring social justice, relying on principles of circularity, efficiency, innovation, renewal, transparency, and responsibility. The authors of these models (Figure 4) have made significant contributions to the development and popularization of sustainable development concepts. Their work encourages a deeper understanding of the connections between economic activity, environmental safety, social well-being, and provides practical tools for implementing these principles in everyday life and business.

The implementation of these models requires joint efforts from businesses, government, and civil society to develop effective policies, invest in cutting-edge technologies, and change consumer behavior. The identified principles will allow achieving a balance between present needs and preserving resources for future generations, while also stimulating economic growth and social progress.

Let’s consider the Ukrainian and global experience in implementing the principles of sustainable development in the context of Industry 4.0 (Table 1–2).



Figure 4 – Modern models of sustainable development in the context of Industry 4.0

Source: formed on the basis of [5–14]

Table 1 – Experience in implementing the principles of sustainable development in accordance with Industry 4.0 in Ukraine

№	Company Name	Description of experience in accordance with the principles of sustainable development
1	TOV “Organic Milk”	The company implements a quality and product safety management system, which includes control over animal feeding and health, and complies with environmental protection requirements. Farms are powered by electricity using solar panels, which is an example of green technology implementation.
2	TOV SP “Nibulon”	The company takes comprehensive measures to reduce its impact on the environment, including the modernization of its fleet for grain transportation by waterways, significantly reducing carbon dioxide emissions compared to using automotive transport.
3	PJSC “Ternopil Dairy Plant” (Molokia)	The company utilizes energy-efficient technologies in dairy production, particularly water purification systems and energy-saving equipment on dairy farms.
4	TOV “Ukrproduct Group”	The company actively implements its own programs for the use of renewable energy sources and emissions reduction.
5	PJSC “Kyiv Confectionery Factory “Roshen”	The company reduces the use of plastic packaging and implements its own waste disposal system at its production facilities.
6	PJSC “Chumak”	The company is working on improving processes related to water and energy use in its production with the aim of reducing its ecological footprint.
7	PJSC “Obolon”	The company implements energy-efficient technologies, waste management systems, water and energy consumption control to reduce the environmental impact of its activities.

Source: formed on the basis of [16–22]

Table 2 – Worldwide experience in implementing sustainable development principles in the context of Industry 4.0

№	Company Name	Description of experience in accordance with the principles of sustainable development
1	Danone	The company actively integrates sustainable development into its strategies, utilizing renewable energy sources and reducing environmental impact.
2	Nestlé	The company implements programs using renewable materials to create recyclable, reusable packaging to reduce plastic usage, and initiates climate change mitigation efforts.
3	Unilever	The company integrates sustainable development principles into its business model by sourcing agricultural products from resilient sources, reducing water consumption, and carbon emissions in its production facilities.
4	Beyond Meat	The company specializes in plant-based meat substitutes, reducing environmental impact by applying alternative animal farming models compared to traditional methods.
5	Impossible Foods	The company produces plant-based meat, demonstrating examples of innovation in the food industry to reduce environmental impact. Its products help reduce reliance on animal agriculture.
6	BrewDog	The company in the beer production industry implements innovations in sustainable production and marketing.

Source: formed on the basis of [23–28]

According to the data in Table 1, it can be concluded that Ukraine’s experience in sustainable development demonstrates the active implementation of innovative approaches and technologies among enterprises in various sectors. Companies such as TOV “Organic Milk” [16], TOV SP “Nibulon” [17], PJSC “Ternopil Dairy Plant” (Molokia) [18], TOV “Ukrproduct Group” [19], PJSC “Kyiv Confectionery Factory “Roshen” [20], PJSC “Chumak” [21], PJSC “Obolon” [22] are implementing measures aimed at ensuring environmental sustainability, optimizing resource use, reducing environmental impact, and increasing energy efficiency. This includes the use of solar energy, equipment modernization, plastic reduction, waste management, efficient water and energy use, and the utilization of renewable energy sources. Such actions not only contribute to improving the environment but also support economic efficiency and corporate social responsibility, highlighting the importance of integrating sustainable development principles into corporate strategy. Ukrainian experience underscores the importance of a comprehensive approach to sustainable development, including innovations in responsible consumption and production.

The analyzed global experience of implementing sustainable development (table 2) demonstrates that leading global companies such as Danone [23], Nestlé [24], Unilever [25], Beyond Meat [26], Impossible Foods [27], and BrewDog [28] actively integrate environmentally responsible practices into their operations. These companies implement innovative technologies and strategies aimed at reducing environmental impact, utilizing renewable materials, developing environmentally friendly packaging, and waste management programs. Companies specializing in plant-based meat substitutes, such as Beyond Meat [26] and Impossible Foods [27], make significant contributions to reducing greenhouse gas emissions, showcasing the potential for reducing the environmental footprint of the food industry. BrewDog [28] is recognized for its efforts in nature conservation, biodiversity preservation, and innovations in production and marketing oriented toward sustainable development. These examples underscore the importance of corporate responsibility and an innovative approach in achieving sustainable development goals, demonstrating that a balanced combination of economic efficiency, environmental sustainability, and social responsibility is key to success in the modern world. Comparing

Ukrainian and global experiences in implementing principles/technologies of sustainable development, it can be concluded that both practices demonstrate active application of innovative technologies and strategies to reduce environmental impact, optimize resource utilization, and enhance energy efficiency. Ukrainian companies should adopt the experience of international companies in packaging innovations, waste management programs, and the development of products that contribute to reducing greenhouse gas emissions. Special attention should be paid to the development of environmentally friendly products and the implementation of comprehensive nature conservation programs. This will not only improve environmental indicators at the national level but also provide Ukrainian companies with competitive advantages in the international market. Having examined contemporary models of sustainable development and analyzed the Ukrainian and global experiences in implementing sustainable development principles, let's develop a framework for implementing sustainable development principles in Ukrainian food enterprises within the context of Industry 4.0 (Figure 5). Should be noted that the developed framework for implementing sustainable development principles in Ukrainian

food enterprises in the context of Industry 4.0 (Figure 5) is crucial for Ukrainian businesses striving for innovation, efficiency, and environmental responsibility. The implementation of this framework requires the involvement of qualified professionals, investment in cutting-edge technologies and infrastructure development, as well as the adaptation of corporate culture to sustainable development principles. Successful implementation promises not only improvements in environmental indicators but also economic benefits through increased efficiency, cost reduction, and the opening of new market opportunities.

Equally important is active collaboration with stakeholders, including government, educational institutions, business communities, and the public, to create a favorable innovation-oriented environment focused on sustainable development.

Conclusions. The implementation of sustainable development principles in the context of Industry 4.0 at Ukrainian food enterprises is a strategically important step that addresses global challenges such as climate change, environmental safety, and social responsibility. The results of the conducted research confirm that digital transformation in the food industry plays a key role in minimizing



Figure 5 – Framework for implementing sustainable development principles in Ukrainian food enterprises within the context of Industry 4.0

Source: developed by the author based on their own research

environmental impact and resource conservation. Modern principles, technologies, and models of sustainable development are based on the application of biodegradable packaging, the use of alternative energy sources, the implementation of energy-efficient technologies, and waste management systems. These innovations facilitate an efficient transition to a circular economy. Equally important is the issue of education and skills development for effectively working with advanced Industry 4.0 technologies and sustainable development, increasing awareness, acquiring new skills, and fostering an innovative culture among personnel. Such an approach ensures not only technological renewal but also the formation of corporate responsibility and ethics. Ukrainian experience in implementing sustainable development principles and technologies in the food industry demonstrates significant potential but also requires a comprehensive understanding of challenges and the search for more effective solutions regarding packaging innovations, waste management programs, and the development of products that contribute to reducing greenhouse gas emissions. The developed framework involves the interaction of technological innovations, sustainable resource management, production efficiency, and social

responsibility, ultimately aimed at achieving sustainable development goals. Key steps in implementing sustainable development principles include analyzing the current state of food enterprises, defining strategic sustainable development goals, integrating advanced technologies considering production specifics, developing and implementing pilot projects, monitoring the impact, and adjusting the strategy. An important aspect will be interaction with stakeholders, government, scientific institutions, business associations, consumers to ensure transparency of proposed initiatives and engage the public in a dialogue about the importance of sustainable development both in the industry and socially. It is also worth noting that sustainable development is not a static goal but a dynamic process that requires constant analysis, assessment, and adaptation of strategies considering changes in technologies, market conditions, and socio-economic environment.

Further implementation of Industry 4.0 technologies in the Ukrainian food industry with a focus on sustainable development provides a unique opportunity not only for industry growth and development but also for improving the quality of life for the population and preserving the natural environment for future generations.

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ВПРОВАДЖЕННЯ ПРИНЦИПІВ СТАЛОГО РОЗВИТКУ НА ХАРЧОВИХ ПІДПРИЄМСТВАХ УКРАЇНИ В КОНТЕКСТІ ІНДУСТРІЇ 4.0

У роботі досліджено проблему впровадження принципів сталого розвитку харчових підприємств України в контекст Індустрії 4.0. Розглянуто та виокремлено основні типи інноваційних технологій у сфері сталого розвитку. Визначено ключові переваги та недоліки застосування технологій сталого розвитку в контексті Індустрії 4.0. Досліджено особливості сучасних моделей сталого розвитку: *CE* (Циркулярна економіка), *Eco-Efficiency* (Екологічна ефективність), *Biomimicry* (Біомімікрія), *Holistic management* (Цілісне управління у сільському господарстві), *SSC* (Ланцюг сталого постачання), *CSR* (Соціальна відповідальність), *C2C* (Від колиска до колиска), *TBL* (Концепція потрібного критерію), *NC* (Природний капіталізм) та модель стейкхолдерського управління. Проведено порівняльний аналіз українського та світового досвіду впровадження принципів та технологій сталого розвитку таких компаній: *Danone*, *Nestlé*, *Unilever*, *Beyond Meat*, *Impossible Foods*, *BrewDog*, ТОВ «Органік Мілк», ТОВ СП «Нібулон», ПрАТ «Тернопільський молокозавод» (Молокія), ТОВ «Укрпродукт Груп», ПрАТ «Київська кондитерська фабрика «Рошен», ПрАТ «Чумаки», ПрАТ «Оболонь». Визначено, що окрім глобальних компаній, серед українських підприємств також присутній досвід практичного впровадження інноваційних підходів та технологій сталого розвитку. Акцентовано увагу на тому, що українському бізнесу слід запозичити досвід глобальних компаній щодо пакувальних інновацій, утилізації відходів та розробці екологічної продукції, з метою покращення екологічних показників на національному рівні. За результатами проведеного дослідження розроблено фреймворк впровадження принципів сталого розвитку на харчових підприємствах України в контексті Індустрії 4.0, який включає кроки від визначення цілей до моніторингу та оцінки. Підсумовуючи результати проведеного дослідження зроблено висновок про необхідність використання підприємствами харчової промисловості інноваційного підходу до сталого розвитку в умовах Індустрії 4.0 для розробки нових стратегій розвитку, розширення ринків збуту та підвищення конкурентоспроможності бізнесу з виробництва харчової продукції.

Ключові слова: сталий розвиток, Індустрія 4.0, харчові підприємства, фреймворк, імплементация.