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A circular ecosystem for the implementation of sustainable development goals based on extended producer responsibility

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Abstract Effective waste management is key to ensuring sustainable development in Ukraine. This study aims to explore the role of extended producer responsibility (EPR) and the circular economy in the implementation of sustainable development goals. This paper provides a comprehensive assessment of the responsible waste management sector in Ukraine. Negative trends such as an increase in waste volume, a decrease in productivity, and a failure to achieve target recycling and disposal levels were identified. This indicates the need for systemic transformations in waste management. The authors demonstrated that the implementation of EPR and circular economy principles is of key importance for overcoming the identified problems. EPR will encourage manufacturers to eco-design products and develop waste recycling infrastructure. The implementation of the circular economy concept requires a comprehensive approach that includes clear legislative regulation, developed infrastructure, financial and nonfinancial incentives, public awareness campaigns, and the integration of the formal and informal waste management sectors. Recommendations are given for the introduction of an effective EPR system, the development of waste recycling infrastructure, ensuring the coherence of legislation and policies, activating the involvement of all stakeholders, and developing scientific research and innovations in the field of the circular economy. The implementation of these measures will contribute to Ukraine's transition to a sustainable circular economy model and strengthen its contribution to the achievement of sustainable development goals. The scientific novelty of the study lies in the development of a methodological framework for a comprehensive assessment of the responsible waste management sector, the identification of key trends in the implementation of sustainable development goals, and the modeling of the equilibrium network interaction of the circular ecosystem. Prospects for further research relate to deepening the study of EPR mechanisms, the specifics of circular economy implementation, and the assessment of its effects.

Keywords: extended producer responsibility, circular economy, sustainable development, waste management, Ukraine

1. Introduction

Modern patterns of consumption and demand are far ahead of the ability of our planet to recover. Therefore, the transition of society at all levels to the principles of a circular economy is being updated. The basis of the modern concept of circularity is the transformation of all waste into something valuable and, as a result, the destruction of linear models of production and consumption (Hemidat et al., 2022; Tamasiga et al., 2022).

Recent years have experienced many successful examples of the transition to the principles of circularity. In global practice, there is already a transition from the current linear growth model to a circular one. Currently, well-known companies (Caterpillar, Philips, Nike, Airbnb and others) are successfully implementing circular economy business models. It is important to scale circular innovations to rethink the transition from linearity to a circular cycle (Silva et al., 2019; Zavhorodnii et al., 2021). In the period of postwar recovery of the economy of Ukraine, the task of effective waste management, which is declared in the Plan for the Recovery of the State in an Ecological Directions, will become especially relevant (Draft plan for the recovery of Ukraine, 2022).

To realize the goals of sustainable development (Abreu & Ceglia, 2018; Barros et al., 2021), further research on the

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formation of a circular ecosystem (Johnson, 2022) is needed to conduct a more holistic analysis that would allow combining more important elements of extended producer responsibility to strengthen socially just development that preserves the environment (Campbell-Johnston et al., 2020; 2021).

Thus, the transition to a circular economy for market participants means, first, the adoption of holistic, system-wide thinking regarding the entire ecosystem and value chain, organizational cooperation mechanisms for scaling circular initiatives, and targeted investment in the development of the circular economy. That is, the need to cooperate in all industries and sectors is becoming increasingly urgent. For this reason, companies are already teaming up with startups, civil society, academia and the public sector to develop innovative solutions and stimulate new forms of innovation. Currently, the leading countries of the world already have vivid examples of cooperation programs, creating space for research and interdisciplinary communities and climate innovators to achieve a common goal: climate neutrality (Circular Economy Forum Austria, 2024).

One of the spheres of implementation of the Action Plan of the European Green Course is "zero pollution". At the same time, the main areas of development of socially responsible businesses in Ukraine in the field of environmental protection are classified as waste disposal by Concept No. 66-r dated January 24, 2020 (Cabinet of Ministers of Ukraine, 2020). The priority of the development of the field of waste management determines the need for a comprehensive assessment of its condition on the basis of sustainable development and a circular economy.

The purpose of this study is to substantiate the fundamental role of the circular ecosystem in the implementation of the goals of sustainable development on the basis of extended producer responsibility.

The following research questions (RQs) are proposed for consideration:

RQ1: To develop methodological recommendations for comprehensive assessment of the sphere of responsible waste management;

RQ2: Using the developed methodological recommendations and a system of indicators, conduct a comprehensive assessment of the sphere of waste management in Ukraine;

RQ3: On the basis of the received analytical data, to determine the key trends in the implementation of the goals of sustainable development and to determine the expected (possible) trends of the state and structural changes of the extended producer responsibility system in the postwar period;

RQ4: To develop an equilibrium model of network interaction for the active implementation of ecological innovations and change management through the transformation of the business model of the circular economy, provided that the criterion for ensuring and qualitative changes is the resultiveness of the circular ecosystem.

2. Literature review

The circular economy is one of the strongest levers humanity has at its disposal for systemic change and transformation of the economy and society. The transition to a circular economy has become an irreplaceable strategic course for businesses, which creates additional financial and economic value (Negrete-Cardoso et al., 2022; Mandpe et al., 2022). For business entities, this is a direction of innovative development, the creation of new competitive advantages and the creation of new markets (Morales et al., 2021; Saarinen & Aarikka-Stenroos, 2022; Zerkina et al., 2022). At the beginning of the formation of the concept of the circular economy, most scientists equated it with recycling processes, as evidenced by the "3-R" system (Geissdoerfer et al., 2017; Korhonen et al., 2018). Currently, the circular economy system has been expanded to "10-Rs" (Figure 1), and the process of its transformation continues.

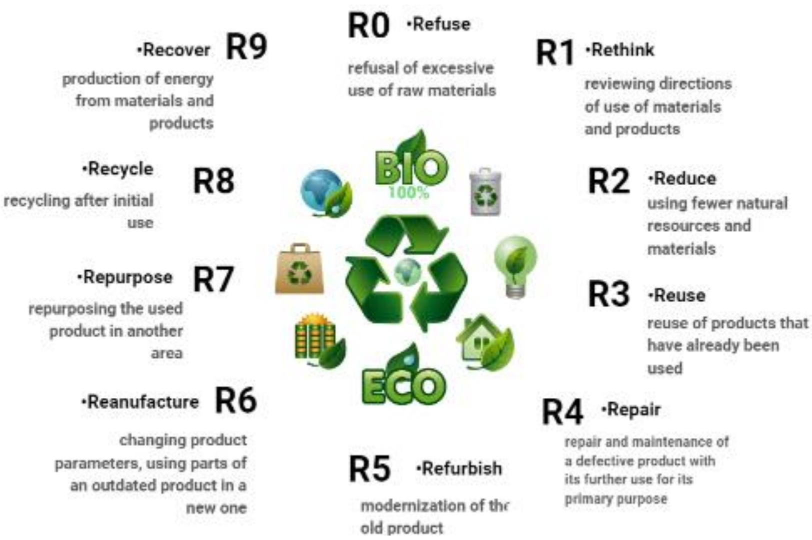

Figure 1 10-R-principles of the circular economy system. Source: (Reike et al., 2017; Asante et al., 2022).

As an alternative to the linear model, the circular economy is aimed at minimizing the consumption of primary raw materials while simultaneously maximizing the use of recycled resources (Stuchtey & Kranendijk, 2018; Diaz et al., 2022). It is based on closed cycles with multiple uses of resources and a high degree of waste processing. Scientists define the circular economy as a restorative and regenerating system that is based on cyclical resource flows and provides for the formation of innovative solutions that synthesize ecological and economic aspects, creating a social basis for inclusive and sustainable development (Geissdoerfer et al., 2017; Korhonen et al., 2018; Asante et al., 2022).

The circular economy contributes to the optimization of production and consumption systems through the implementation of a nonlinear economic model based on the eco-innovative interaction of nature and man. It is the basis for increasing the social and environmental responsibility of business entities based on resource-saving consumption, the introduction of clean production with low emissions, and waste prevention systems, as well as strengthening the responsibility of consumers through eco-labeling and "green" public procurement (Baars et al., 2021; Faibil et al., 2022).

The development of extended producer responsibility (OECD, 2024) is the basic basis for the active implementation of environmental innovations and change management through the transformation of the circular economy business model (Gui, 2020; Faibil et al., 2022; Filyppova et al., 2021) by changing the institutional environment of the urban waste regime (D’Amico et al., 2021; Ibn-Mohammed et al., 2021). As an important circular economy tool, extended producer responsibility has been implemented worldwide since the 1980s (Joltreau, 2022; Rubio et al., 2019; Vernier, 2021). Extended producer responsibility schemes vary across countries in terms of product characteristics and local institutional contexts. Prolonged producer responsibility has undergone significant evolution, adapting to ever-changing environmental management under the conditions of the transformation of transnational flows of products and services (Campbell-Johnston et al., 2020, 2021; Kunz et al., 2018). Therefore, the study of the features and results of the implementation of extended producer responsibility in different countries of the world is being updated.

A condition for the implementation of circularity in solving waste management tasks as a basic economic model is the participation of business organizations, the government, consumers and the public, which requires cultural transformations of society (Rizos & Bryhn, 2022; Bondarenko et al., 2021). Therefore, in a circular economy, connection to a wider ecosystem, i.e., networking and collaboration across the value chain, in related industries and between different regions, is particularly important (European Commission, 2020). Such interaction involves close cooperation with investors, governments, nongovernmental organizations, academia, etc.

The biological term "ecosystem" was adapted to business by Moore (1993), who suggested considering the enterprise in the context of its interaction with other organizations and participants. The term "business ecosystem" was introduced, meaning such a system of groupings that develop dynamically and on a common basis, which include various subjects that create and receive new content and content in the process of both interaction and competition (Moore, 1993). According to Moore (1993), the dynamism and uncertainty of the external environment determine the need for cooperation and cooperation, and for business success, the need to develop "environmental awareness". In this sense, advantages in competition arise from ideas about when and how to build ecosystems, how to form their infrastructural support and institutional bases of management and regulation, and how to ensure their growth and constant improvement. According to experts, the business ecosystem is formed at the junction of technologies, open standards and architecture, which provides a platform for the development of enterprises in adjacent markets of the industry (Jacobides et al., 2018; Ibn-Mohammed et al., 2021). The keyword “circular ecosystem” in the Scopus scientometric database revealed 3197 publications for the period 2000-2024. The keyword cloud of these publications is shown in Figure 2.

Figure 2 Cloud of the most used keywords on the subject of the study circular ecosystem.

By analyzing the frequency of keywords in publications on the topic of “circular ecosystem” in the Scopus database for the period 2000-2024, the following patterns can be identified:

“Circular economy” is the most common keyword (984 occurrences), which indicates a close connection between the concept of a circular ecosystem and the ideas of a circular economy.

The words “ecosystem” (468), “ecosystem” (449), and “ecosystem” (125) have a high frequency, reflecting the ecological component of circular systems. Keywords related to sustainable development are also frequently used: “Sustainable Development” (467), “Sustainability” (370), “Environmental Impact” (167), “Environmental Protection” (118), “Environmental Economics” (95), “Environmental Management” (87), and “Environmental Sustainability” (65). There are also words related to waste and resource management: “recycling” (237), “waste management” (205), “waste disposal” (53), “plastic waste” (73), and “wastewater treatment” (97). There are terms related to the assessment of the life cycle of products: “Life Cycle” (146), “Life Cycle Assessment” (85), and “Life Cycle Analysis” (54). A cluster of biological terms was identified: “Animals” (191), “Animal” (161), “Biodiversity” (184), “Species Diversity” (62), “Species Richness” (51), “Genetics” (98), and “Phylogeny” (84).

Economic aspects are reflected in the words “Economics” (122), “Economic Aspect” (115), “Industrial Economics” (62), and “Business Models” (52). There are terms related to energy and climate change: “Biomass” (138), “Climate Change” (206), “Greenhouse Gases” (62), “Carbon” (87), and “Carbon Dioxide” (56). There are also geographical names, such as “China” (125) and “United States” (79), which may indicate the leading role of these countries in circular ecosystems research.

These patterns illustrate the interdisciplinary nature of circular ecosystem research, which encompasses the environmental, economic, technological, and social aspects of sustainable development. Researchers argue that in today's economy, competitive advantage is provided by innovation, the success of which requires increased cooperation or a network of organizations in which all players share a common vision of how to innovate (Jacobides et al., 2018).

To realize the potential of the ecosystem, it is important to focus on the following key areas: exchange, cooperation, investment and politics (Figure 3).

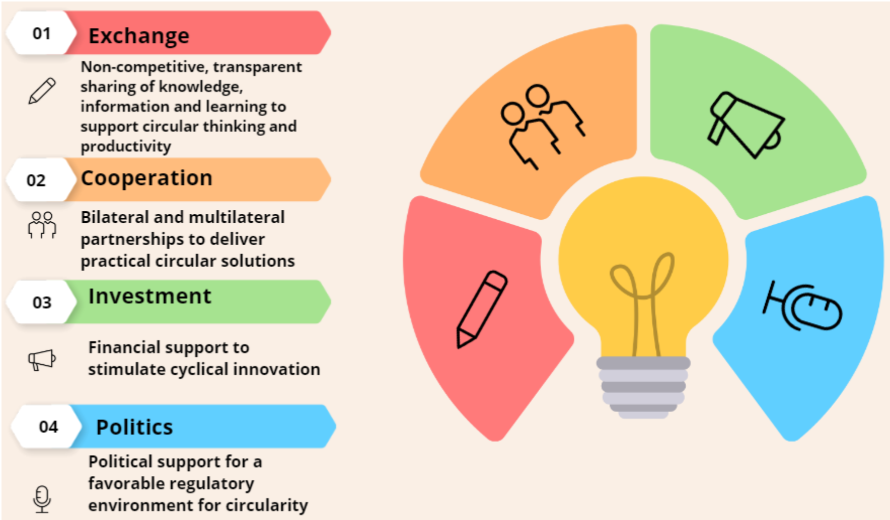

Figure 3 Key directions for realizing the potential of circular ecosystems.
Source: Salvador et al., 2021; Ibn-Mohammed et al., 2021.

The exchange is a noncompetitive, transparent exchange of knowledge, information with industry local or regional partners, and training to support circular thinking and productivity.

Partnerships based on such exchanges can significantly accelerate the deployment of a circular economy. Collaboration is a bilateral or multilateral partnership that delivers practical circular solutions that benefit everyone. Investments are financial support to stimulate cyclical innovation: in innovative start-ups, product and business model development, intellectual leadership, and research and development by noncommercial third parties, such as nongovernmental organizations or academia. Political support for an enabling regulatory environment for circularity: engaging in local and national debates as well as international forums to inform and/or influence relevant policy measures and regulations that would promote a regional and global circular economy.

Thus, the implementation of circular economy principles is critical for ensuring sustainable development and achieving sustainable development goals (SDGs). The circular economy involves the creation of closed production and consumption cycles where waste is minimized and materials are reused and recycled.

This concept is reflected in the creation of “circular ecosystems”, where all participants—producers, consumers, and recyclers—interact to ensure circularity.

EPRs play an important role in building such circular ecosystems. EPR obliges manufacturers to take responsibility for managing the waste generated by the consumption of their products. This encourages companies to develop more environmentally friendly and recyclable products and to develop waste collection and recycling infrastructure.

The implementation of the EPR program and the circular economy are closely linked to the achievement of the SDGs. In particular, it contributes to the realization of Goal 12, “Responsible Consumption and Production”, by reducing waste and increasing resource efficiency. In addition, circular approaches also have a positive impact on Goal 13, “Mitigate climate change”, by reducing greenhouse gas emissions, and Goal 15, “Protect terrestrial ecosystems”, by conserving natural resources

(Ajwani-Ramchandani & Bhattacharya, 2022; Chenavaz & Dimitrov, 2024).

The successful implementation of the EPR program and the circular economy requires a comprehensive approach that includes clear legislative regulation, developed waste collection and recycling infrastructure, financial and nonfinancial incentives for producers, public awareness, and the integration of the formal and informal waste management sectors (Islam et al., 2022; Hossain et al., 2022). At the same time, it is important to take into account the specifics of different industries where circular approaches are implemented.

In general, the creation of circular ecosystems based on EPR and other circular economy tools is key to ensuring sustainable development and achieving the SDGs. A comprehensive and industry-specific approach is key to the effectiveness of such transformations. Therefore, the hypotheses (H) of this study are as follows:

H1: A condition for the development of the circular economy is the formation and effective functioning of the ecosystem of innovations as a tool for the implementation of the strategy of technological development, which ensures the convergence of knowledge in technologies and the expected solutions.

H2: To realize the goals of sustainable development, it is necessary to form a multilevel system (circular ecosystem) and create a circular adaptation and innovation environment based on the principles of extended producer responsibility.

H3: The circular ecosystem should provide institutional conditions for innovation processes and regulation at all levels of interaction between innovators, institutions, the state, the market and enterprises.

Therefore, circular ecosystems should unite the efforts of authorities, scientific organizations, private and public corporations, investors, managers of small enterprises, innovative companies, clusters, technological platforms, engineering companies and technology parks.

3. Methodology

The effectiveness of circular systems is achieved by restoring the value of used goods while simultaneously reducing the negative impact on the surrounding natural environment, which corresponds to the priorities of sustainable development. The basic methodological platform of this study is the concept of sustainable development (Ministry of Economic Development and Trade of Ukraine, 2017; UNDP, 2017). Analytical research of the main keywords in the selected areas made it possible to form a structural and logical scheme for the scientific search (Figure 4).

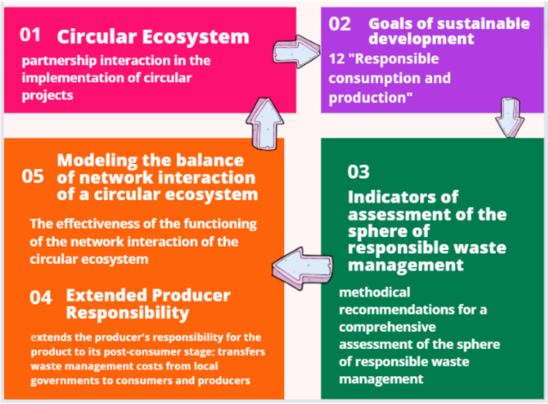

Figure 4 Structural and logical scheme of research based on keywords.

To achieve the goal of this research, a system of general scientific and special methods and approaches was used, in particular, general, general scientific, interdisciplinary and special research methods.

To generalize and systematize the categorical apparatus and highlight modern vectors of scientific research from the given problem, a descriptive analysis based on the sources of the Scopus scientometric database was used. The study included:

Step 1. Circular ecosystem, partner interaction in the implementation of circular projects.

Step 2. Sustainable development goals: 12 "Responsible consumption and production".

The principles of the circular economy are aimed at the formation of socially responsible production and consumption and are correlated with the directions of sustainable development of the state, in particular, Sustainable Development Goal 12 "Responsible consumption and production". The fourth task of this goal envisages reducing the volume of waste generated and increasing the amount of waste being processed and reused based on innovative technologies and production.

Step 3. The authors created a set of indicators for a comprehensive assessment of the sphere of responsible waste management.

At the same time, the primary importance of the field of waste management for the development of socially responsible businesses in the direction of environmental protection is taken into account in accordance with Concept No. 66 of the year. dated January 24, 2020 (Cabinet of Ministers of Ukraine, 2020), as well as the implementation of the European Green Course Action Plan, which is the basis of Ukraine's postwar recovery plan in the direction of "environmental safety and effective waste management" (National Council for the Reconstruction of Ukraine from the Consequences of War, 2022). Table 1 presents a set of indicators for assessing the area of responsible waste management.

Table 1 Methodological recommendations for a comprehensive assessment of the sphere of responsible waste management.

Goals of sustainable development, tasks	Main indicators
1. Dynamics of volumes of generated waste and waste productivity of gross domestic product (GDP) Sustainable development goal 12 "Responsible production and consumption" Task 12.4 "Reduce the volume of generated waste and increase the volume of its processing"	1. Index of generated waste of classes I-IV, in % until 2015 ** 2. Index of household and similar waste per 1 person, in % until 2015 ** 3. Waste capacity of GDP, kg/thousand dollars. USA, purchasing power parity 2017 * 4. GDP waste productivity, hryvnias/ton (at constant 2016 prices) *** 5. GDP waste productivity index, in % until 2015. *** 6. Productivity of GDP by household and similar waste, thousand UAH/ton (at constant 2016 prices) ** 7. GDP productivity index by household and similar waste, in % until 2015 **
2. The general state of the field of waste management Task 12.4 "Reduce the volume of generated waste and increase the volume of its processing and reuse based on innovative technologies and production"	1. The share of incinerated and disposed waste in the total amount of generated waste, % * 2. Index of recycled waste of classes I-IV, in % until 2015 ** 3. Index of class I-IV waste disposed of in specially designated places or facilities, in % by 2015 ** 4. The share of waste disposed of in specially designated places or objects in the total amount of generated waste, % ** 5. Index of waste accumulated during operation at waste disposal sites, in % until 2015 **
3. Sectoral and investment dimension of the field of waste management To increase the volume of waste processing by sectors of the economy, the volume of investment in the field of waste management	1. Index of generated waste by sectors of the economy, in % until 2015 ** 2. Changes in the sectoral structure of waste compared to 2015, % ** 3. Sectoral waste productivity of gross added value, in comparable prices of 2016, kg/thousand UAH.** 4. Index of sectoral waste productivity of gross added value, in % until 2015 ** 5. The share of investments in waste management in the total costs of environmental protection, % ** 6. Investment index for waste management per 1t of generated waste, hryvnias/t** 7. Sectoral capital investments for waste management per 1 ton of generated waste of a certain sector, UAH/t **

Source: * National indicators of sustainable development (UNDP (2017). ** The indicator was proposed by the authors. *** Indicators according to the OECD methodology (Ministry of Economic Development and Trade of Ukraine, 2016).

In the structure of indicators of a comprehensive assessment of the sphere of responsible waste management, the author's indicators (79%) are dominated by indicators aimed at assessing the dynamics of sectoral waste productivity of gross added value (at constant 2016 prices), changes in the sectoral structure of generated waste, and the dynamics of specific investments in waste management on 1 ton of waste both in the state and sectoral dimensions, which allows us to determine the state of responsible waste management of certain sectors of the economy. It should be noted that such an assessment can serve as a strong analytical basis for the development of effective waste management measures in the sectors of the national economy in the postwar period. Expert assessment of the state of responsible waste management in the system of the national economy (macro level) is the final stage of the developed methodological recommendations. The expert assessment is based on the results of the analysis of quantitative indicators of responsible waste management, covering the developed system of indicators (Table 1).

To carry out an expert assessment of the level of responsible waste management (RWM) in Ukraine, we use a 5-component scale that identifies five types of point assessments: (1) low, 0-2 points; (2) below average, 2.1-4 points; (3) average, 4.1-6 points; (4) higher than average, 6.1-8 points; and (5) high, 8.1-10 points (Figure 5).

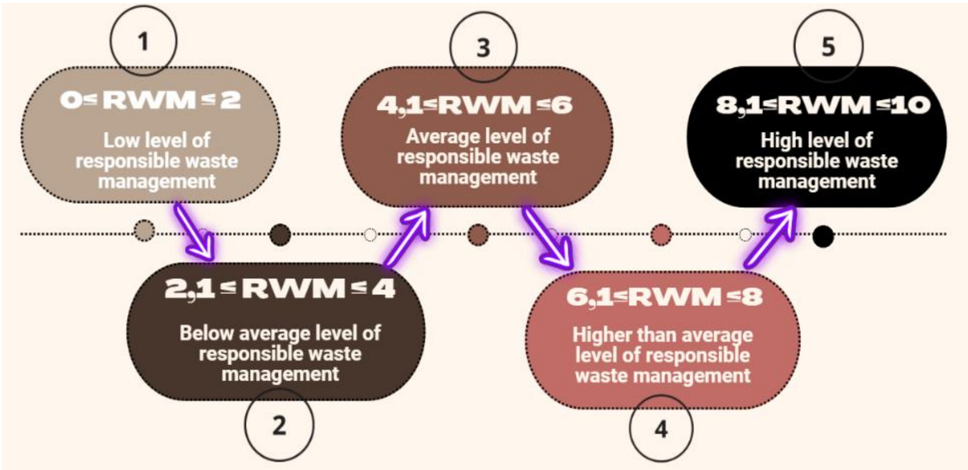

Figure 5 The scale of identification of the level of responsible waste management in the state.
Source: Developed on the basis of (Popadyuk, 2018; Stratiychuk 2022).

The state (or regional) economy can be considered socially responsible if the integral indicator of responsible waste management, which includes partial indicators for three areas of comprehensive assessment taking into account their importance, is at least 4, i.e., has an average or higher average level (Figure 5). The results of a comprehensive assessment of the state of responsible waste management in Ukraine provide a sufficient analytical basis for conducting an expert survey of experts on environmental management, sustainable development of the state and society, and various stakeholders. This analytical tool is the basis for the formation of a system of extended producer responsibility.

Step 4. Extended producer responsibility is an element and a scientific and practical approach of environmental business policy that will contribute to the creation of incentives for innovative products with less impact on the environment during the life cycle (Kunz et al., 2018; Petit-Boix et al., 2022). Extended producer responsibility extends producer responsibility, physical and/or financial, for a product to its postconsumer stage and shifts the costs of waste management from local governments to consumers and producers (Carayannis et al., 2012; Chambers et al., 2019; Rahmani et al., 2021). Such a political strategy affects not only the physical properties of the product but also environmentally responsible methods of consumption and production.

Step 5. Modeling the Equilibrium of Network Interaction of a Circular Ecosystem

The basis of the network interaction of a circular ecosystem is the project cycle management methodology. According to this methodology, environmentally oriented project management processes form a project cycle consisting of six stages: programming, identification, wording, financing, implementation, assessment and audit. Circular projects should meet the goals of the integrated strategy of all partners creating a network system. At the same time, projects should be developed on the basis of an agreed upon strategy and address the pressing problems of the target groups/parties whose needs the projects are aimed at. Projects must be realistic from a practical point of view; that is, their goals are considered achievable, taking into account the limitations of the execution environment and the capabilities of the network system organizations involved in the implementation of the projects. The results achieved within the projects should be permanent. For the implementation of circular projects, logframe analysis is used, as well as other tools for analyzing/evaluating key aspects (for example, problems, goals and strategies). On the basis of such an analysis, a set of safety characteristics is determined for the implementation of the project. In the future, such indicators will act as indicators for evaluating the effectiveness of the project and, therefore, the effectiveness of the created circular network system—a circular ecosystem.

To ensure the comprehensiveness and objectivity of the assessment of the responsible waste management sector, this study used a system of general scientific and special methods.

First, an analytical study of the main keywords in the relevant scientific areas was conducted. This allowed us to form a structural and logical scheme of scientific research (Figure 4) and identify key thematic blocks.

To summarize and systematize the categorical apparatus and to identify modern vectors of scientific research on this issue, a descriptive analysis based on the sources of the Scopus scientometric database was used. The study included the following main stages:

Analysis of the circular ecosystem concept and partnerships in the implementation of circular projects. Research of the Sustainable Development Goals, in particular Goal 12 “Responsible consumption and production”. Development of a system of indicators for a comprehensive assessment of responsible waste management.

The following key criteria were taken into account when developing a system of indicators for assessing responsible waste management: the clarity and unambiguity of the interpretation of indicators to ensure the objectivity of the assessment. Availability and reliability of the statistical data required for the calculation of indicators. Representativeness of indicators for different aspects of waste management. Compliance with the Sustainable Development Goals, particularly Goal 12. It is possible to conduct a comparative analysis of the dynamics and sectors of the economy. The proposed system of indicators was discussed and finalized by experts. Its use allows for a comprehensive assessment of the state of responsible waste management at the macro level. The final stage of the methodology was an expert assessment of the level of responsible waste management in Ukraine on a 5-point scale. This made it possible to form an analytical basis for developing effective waste management measures in the sectors of the national economy in the postwar period.

4. Results

4.1. The current state of the field of waste management in Ukraine

Using the developed methodological recommendations and a system of indicators (Table 1), we will conduct a comprehensive assessment of the sphere of waste management in Ukraine. The main indicators characterizing the waste capacity and waste productivity of the GDP are summarized in Table 2. In 2020, 462.37 million tons of class I-IV waste were generated, representing an increase of 48.1% compared to 2015. At the same time, the volume of generated households and similar waste reached 6.67 million tons, a decrease of 1.7% compared to the base period. In the reporting year, the indicator of waste capacity of GDP amounted to 894.9 kg/thousand dollars. purchasing power parity in 2017, practically reaching the target value of the indicator in 2025, exceeding the target value of the indicator in 2020 by 6.9% (880 kg/thousand dollars of purchasing power parity) (UNDP, 2017).

Table 2 Dynamics of indicators of waste capacity and waste productivity of GDP in Ukraine

Indicators	Years					
	2015	2016	2017	2018	2019	2020
1. Volumes of generated waste of classes I-IV, thousand tons	312268	295870	366054	352334	441517	462374
% by 2015	100,0	94,7	117,2	112,8	141,4	148,1
2. Volume of generated household and similar waste, thousand tons	6789,2	6946,2	6183,2	6211,2	6618	6672,0
% by 2015	100,0	102,3	91,1	91,5	97,5	98,3
3. Waste capacity of GDP, kg/thousand dollars. purchasing power parity in 2017	648,6	601,1	725,7	675,6	820,1	894,9
GDP waste capacity index	100,0	92,7	111,9	104,2	126,4	138,0
4. GDP waste productivity, hryvnias/ton (at constant 2016 prices)	7456,8	8062,2	6670,2	7171,7	5906,2	5428,1
GDP waste productivity index	100,0	108,1	89,5	96,2	79,2	72,8
5. Productivity of GDP for household and similar waste, thousand UAH/ton (at constant 2016 prices)	343,0	343,4	394,9	406,8	394,0	376,2
GDP productivity index by household and similar waste	100,0	100,1	115,1	118,6	114,9	109,7
6. Volume of generated household and similar waste, kg/person	158,5	162,8	145,5	146,9	157,5	159,8
% by 2015	100,0	102,7	91,8	92,7	99,4	100,9

Source: Developed on the basis of Official website of the State Statistics Service of Ukraine.

The GDP productivity indicator for waste in 2020 amounted to a UAH of 5,428.1/t (at constant 2016 prices), decreasing by 27.2% compared to 2015 (Table 2). The tendency to reduce the waste productivity of GDP in Ukraine in 2017–2020 is due to lower rates of GDP growth at constant prices in 2016 compared to the rates of growth in the volume of generated waste (Figure 6).

The GDP productivity indicator for households and similar waste in the reporting year was 376,2 thousand UAH/t (at constant 2016 prices), an increase of 9,7% compared to the base period.

The growing trend of GDP productivity by household and similar waste in 2017–2020 is due to a reduction in the volume of generated households and similar waste in the country due to a slight increase in GDP at comparable prices in 2016. After a decrease in 2017, the volume of household and similar waste per person slowly increased in 2018–2020; in the reporting year, it reached 159.8 kg/person, which was 0.9% higher than that in the base year (Table 2).

Waste disposal and processing remain urgent problems in Ukraine. In 2020, 462.4 million tons of waste were generated, while only 21.7% of the generated waste was disposed of (Table 3).

The share of incinerated and recycled waste in the total amount of generated waste reached 22% in 2020, which is 23% below the target indicator of sustainable development in 2025 (45%). On the other hand, the amount of waste disposed of in specially designated places or objects is increasing—by 81.2% compared to 2015—or almost 60% of the generated waste.

As a result, 27,12 thousand tons of waste were accumulated per 1 km^2 in Ukraine, which is 25% greater than in 2015 (374,5 tons of waste per person) (Table 3).

In the absence of a developed waste management infrastructure, landfills have become sources of ecological danger, occupying 1/7 of the country's area. Only 78% of the population is provided with household waste removal services, and there are not enough factories for their processing. Therefore, the underdevelopment of infrastructure for the reuse of raw materials is one of the main reasons for the worsening of environmental problems in the field of waste management. In the sectoral structure of generated waste in Ukraine, 84.6% of the waste is from the extractive industry and quarry development, of which

79.4% is waste from the extraction of metal ores (Table 4).

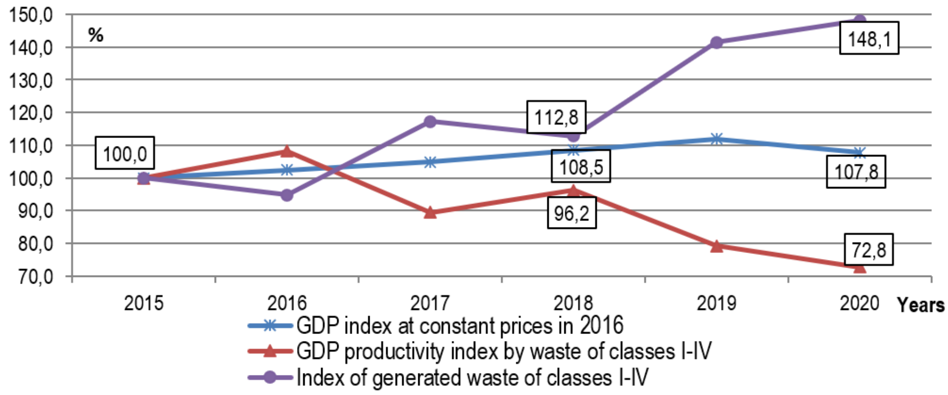

Figure 6 Dynamics of the basic indices of GDP, generated waste and GDP waste productivity in Ukraine (in % until 2015).

Table 3 Dynamics of the volumes of generated, utilized and accumulated waste in Ukraine, million tons.

Indicators	Years					
	2015	2016	2017	2018	2019	2020
1. Class I-IV waste was disposed of	92,5	84,6	100,1	103,7	108,0	100,5
in % by 2015	100,0	91,5	108,2	112,1	116,8	108,7
2. Burned waste	1,13	1,11	1,06	1,03	1,06	1,01
у % до 2015 р.	100,0	97,5	93,8	90,6	93,3	88,8
3. The share of incinerated and disposed waste in the total amount of generated waste, %	30,0	29,0	27,6	29,7	24,7	22,0
4. Removed to specially designated places or facilities	152,3	157,38	169,8	169,5	239,0	276,0
in % by 2015	100,0	103,3	111,5	111,3	156,9	181,2
in % to the volume of generated waste	48,8	53,2	46,4	48,1	54,1	59,7
6. Accumulated during operation at waste disposal sites:	21,69	21,5	21,63	22,50	26,71	27,12
6.1. Per 1 km^2 of the country's territory, thousands of tons						
in % by 2015	100,0	99,1	99,7	103,7	123,1	125,0
6.2. Per person, tons	291,9	289,3	292,9	306,9	366,4	374,5
in % by 2015	100,0	99,1	100,3	105,1	125,5	128,3

Source: Developed on the basis of Official website of the State Statistics Service of Ukraine.

Table 4 Structural and dynamic changes in generated waste in Ukraine by economic sector.

Sectors of the economy	2015 year thousands of tons	%	2018 year thousands of tons	2019 year thousands of tons	2020 year thousands of tons	%	2020 in % by 2015	Structural changes, % (6-2)
1. Agriculture, forestry and fishing	8737	2,8	5968	6751	5315	1,1	60,8	-1,6
2. Extractive industry and development of quarries	257862	82,6	301449	390564	391078	84,6	151,7	+2,0
including extraction of metal ores	238157	76,3	282482	367084	366901	79,4	154,1	+3,1
3. Processing industry, in total, including:	31001	9,9	31523	30752	52311	11,3	168,7	+1,4
3.1. Production of food products	4222	1,4	5818	5581	4159	0,9	98,5	-0,5
3.2. Metallurgical production	20726	6,6	21799	21515	43650	9,4	210,6	+2,8
4. Supply of electricity, gas, steam and air conditioning	6598	2,1	6323	5959	5334	1,2	80,8	-1,0
5. Water supply; sewerage, waste management	594	0,2	397	412	338	0,1	56,9	-0,1
6. Construction	376	0,3	379	189	15	0,0	3,9	-0,1
7. Other types of economic activity	1047	1,9	751	994	2033	0,4	194,1	+0,1
8. From households	6053	2,8	5544	5897	5950	1,3	98,3	-0,7

Source: Developed on the basis of Official website of the State Statistics Service of Ukraine.

The second-largest is occupied by the processing industry, with a share of 11,3% (of which 9,4% is metallurgical production waste), and the third-largest are the energy sector and agriculture, with shares of 1,2% and 1,4%, respectively. The specific weight of household waste in the reporting year reached 1.3%, decreasing by 0.7% compared to the base period. In 2015–2020, the most significant structural change was an increase in the share of waste from the extraction of metal ores by 3.1% and a decrease in the specific weight of agriculture by 1.6% (Figure 7).

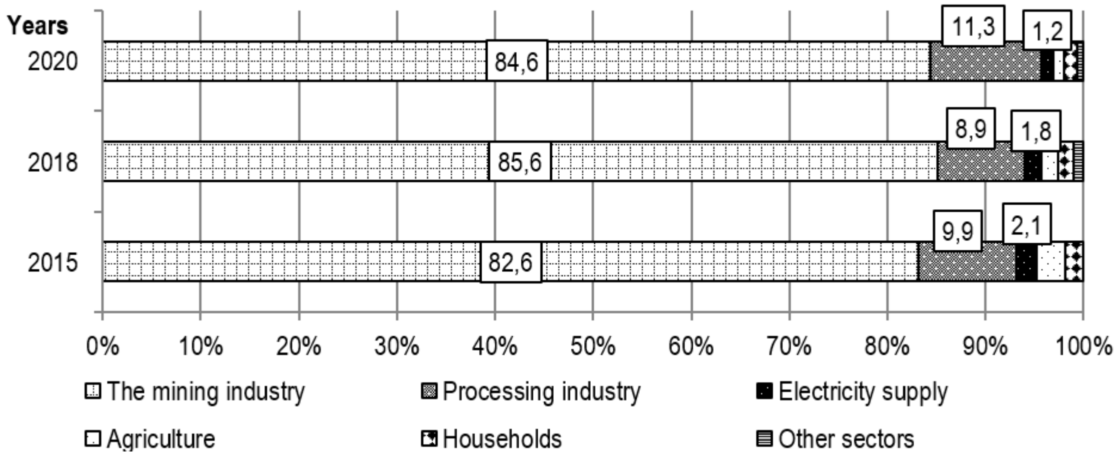

Figure 7 Sectoral structure of generated waste in Ukraine, %.
Source: Developed on the basis of Official website of the State Statistics Service of Ukraine.

During the studied period, the volume of waste in the extractive industry increased by 51.7%, and that in the processing industry increased by 68.7% (including metallurgical waste by 110.6%). The other sectors exhibited a downward trend in terms of the amount of generated waste (Table 4).

In particular, in agriculture, the indicator decreased by 39.2%, in the energy and water supply sectors by 19.2%, and by 43.1%, respectively. In Ukraine, the amount of waste from the extractive industry in 2020 reached 462.4 million tons (Table 4), and this is the largest indicator among European countries. In EU countries, the amount of waste from the extractive industry and the development of quarries are much lower than those in Ukraine. Therefore, in 2016, it amounted to 109.7 million tons in Sweden, 93.66 million tons in France, 70.65 million tons in Poland, 17.1 million tons in Great Britain, and 7.2 million tons in Germany (Ministry of Economic Development and Trade of Ukraine, 2016). Directive 2006/21/EC dated 15.03.2006 "On the management of waste from the extractive industry" is in effect in the European Union states, the main purpose of which is to prevent and minimize any negative impact on the NPS and risks to human health that may arise as a result of extractive industry waste management. The implementation of the provisions of Directive 2006/21/EC in Ukraine is foreseen. The dynamics of the waste productivity indicator of the gross added value (at comparable 2016 prices) of the sectors of the national economy, which occupy a significant share of the structure of generated waste, are presented in Table 5.

Table 5 Dynamics of sectoral waste productivity of gross added value in the compared prices of 2016 in Ukraine, UAH/ton.

Sectors of the economy	Years					
	2015	2016	2017	2018	2019	2020
1. All in the economy	7456,8	8062,2	6670,2	7171,7	5906,2	5428,1
In % by 2015	100,0	108,1	89,5	96,2	79,2	72,8
2. Mining industry	513,0	554,4	393,2	419,9	318,3	308,3
In % by 2015	100,0	108,1	76,6	81,9	62,0	60,1
3. Manufacturing industry	9069,6	8549,3	9420,6	9774,9	10106,4	5598,8
In % by 2015	100,0	94,3	103,9	107,8	111,4	61,7
4. Electricity supply	11066,8	9826,1	11111,3	11207,7	11458,6	12612,3
In % by 2015	100,0	88,8	100,4	101,3	103,5	114,0
5. Agriculture	30107,2	32092,4	44058,4	49418,6	44129,3	50048,5
In % by 2015	100,0	106,6	146,3	164,1	146,6	166,2

Source: Developed on the basis of Official website of the State Statistics Service of Ukraine.

The lowest level of the indicator is characteristic of the most waste-intensive sector—the mining industry and the development of quarries. In 2020, its value reached UAH 308,3/tons, which is 17,6 times lower than the average indicator for the economy. The level of waste productivity of the processing industry is close to the value of the average indicator. For the least waste-intensive sectors of the economy—energy supply and agriculture—the indicator values are above the average level and amount to UAH 121612,3 in the reporting period./t and UAH 50048,5/t, respectively. In 2017–2020, the waste productivity indicator of the extractive industry exhibited a downward trend, which was due to an increase in the volume of sectoral waste (24.7%) against the background of a decrease in the sectoral waste productivity of the gross added value at comparable prices in 2016 (by 2.3%) (Figure 8).

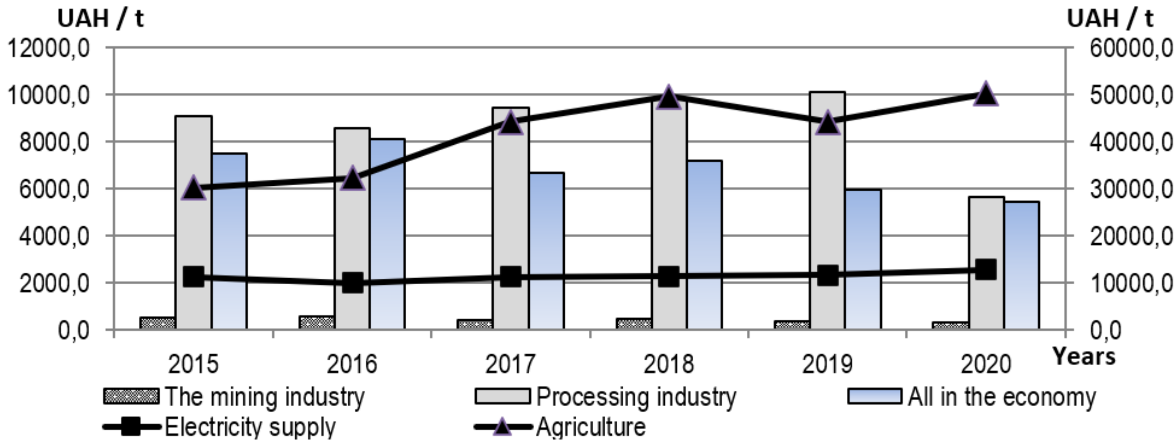

Figure 8 Sectoral waste productivity of gross added value at comparable prices in 2016 in Ukraine, UAH/t.

During this period, the waste productivity of the gross added value of waste in agriculture and the energy supply sector had an increasing trend, caused by the greater rates of reduction in the volumes of waste generated in the sectors compared to the reduction in their gross added value. The results of the expert assessment of the state of responsible waste management in Ukraine according to 19 indicators of sustainable development and "green" growth, taking into account their significance coefficients, are summarized in Table 6.

Table 6 Expert assessment of the field of responsible waste management.

Indicators	Score in points	K sig.*	Score with Ksig
1.1. Index of generated waste of classes I-IV, in % until 2015.	2,0	0,15	0,30
1.2. Index of household and similar waste per 1 person, in % until 2015.	2,9	0,1	0,29
1.3. Waste capacity of GDP, kg/thousand dollars purchasing power parity in 2017	1,7	0,15	0,26
1.4. Waste productivity of GDP, hryvnias/ton (in constant prices of 2016)	1,4	0,15	0,21
1.5. GDP waste productivity index, in % until 2015.	1,2	0,15	0,18
1.6. Productivity of GDP by household and similar waste, thousand UAH/ton (at constant 2016 prices)	2,5	0,15	0,38
1.7. GDP productivity index by household and similar waste, in % until 2015	2,5	0,15	0,38
Total for group 1 "Dynamics of volumes of generated waste and waste productivity"	X	1	1,99
2.1. The share of incinerated and utilized waste in the total amount of generated waste, %	0,9	0,25	0,23
2.2. Index of recycled waste of classes I-IV, in % until 2015	1,5	0,2	0,3
2.3. Index of waste of classes I-IV, removed in specially designated places or objects, in % by 2015	4,1	0,2	0,82
2.4. The share of waste removed to specially designated places or objects in the total amount of generated waste, %	1,1	0,15	0,165
2.5. Index of waste accumulated during operation at waste disposal sites, in % until 2015	2,1	0,2	0,42
Total for group 2 "General state of the field of waste management"	X	1	1,93
3.1. Index of generated waste by economic sectors, in % until 2015	1,5	0,15	0,23
3.2. Changes in the sectoral structure of waste compared to 2015, %	0,5	0,15	0,08
3.3. Sectoral waste productivity, in comparable prices of 2016, kg/thousand UAH.	0,9	0,16	0,14
3.4. Sectoral waste productivity index, in % until 2015.	0,7	0,18	0,13
3.5. Index of investments in waste management per 1 ton of generated waste, hryvnias/t	4	0,18	0,72
3.6. Sectoral capital investments for waste management per 1 ton of generated waste of a certain sector, hryvnias/t	0,5	0,18	0,09
Total according to group 3 "Sectoral and investment dimension of the field of waste management"	X	1	1,38

Source: Generalized results of the expert survey. *Kig. – coefficient of significance.

An expert assessment of the level of responsible waste management in Ukraine was carried out on the basis of a comprehensive assessment of waste productivity of gross added value. All three groups of indicators characterizing the state of the sphere of responsible waste management received low ratings, which is due, in particular, to the lack of positive dynamics of indicators on the way to achieving the goals of sustainable development and the growth of indicators of waste productivity (both general and sectoral).

Considering the coefficients of significance, the overall expert assessment of the state of responsible waste management in the state amounted to 1,77 points, which corresponds to a low level (Table 7).

In the field of waste management, Ukraine lags far behind European countries that have learned to process waste into a resource (goods and energy) and reuse it.

Table 7 Results of an expert assessment of the field of responsible waste management.

Groups of indicators	Score in points	Level	K sig.	Score with K sig
1. Dynamics of volumes of generated waste and waste productivity of GDP	1,99	Low	0,33	0,66
2. The general state of the field of waste management	1,93	Low	0,34	0,66
3. Sectoral and investment dimension of the field of waste management	1,38	Low	0,33	0,46
Total:	X	X	1,00	1,77

Ukraine has not created a developed waste management infrastructure, the volume of which is generated (Table 1) is growing at an accelerated rate compared to the volume of disposal (Table 2).

Currently, only one incineration plant, "Energia", is operating, which allows the disposal of 25% of solid industrial waste. In Ukraine, more than 90% of solid industrial waste is disposed of in landfills (in Sweden, only 1%). There are 6148 landfills, 2600 of which are official. According to EU regulations, their number must be reduced to 500.

An unsolved problem in the development of the circular economy in Ukraine remains the absence of a tariff for waste processing, which contributed to the emergence of the "shadow" segment of the secondary raw materials market (approximately 50%).

4.2. Implementation of sustainable development goals and expected (possible) trends in the state and structural changes of the system of extended producer responsibility in the postwar period of Ukraine

Based on the results of a comprehensive assessment of responsible waste management in three directions, an expert assessment of the state of development of the components of the responsible waste management system, a periodization of the main trends of responsible waste management was carried out, and the expected (possible) trends of the state and structural changes of the system of responsible waste management in the postwar period were determined (Table 8).

Table 8 Periodization of trends in responsible waste management in Ukraine.

Responsible waste management		
Prewar period	War period **	Postwar period **
1. Growth in 2015-2020 of the volumes of generated waste of classes I-IV by 48,1% and the waste capacity of responsible waste management by 38%. 2. Decrease in waste productivity of responsible waste management in constant prices by 27,2%. 3. Relatively constant volumes of household and similar waste generation (6,7 thousand tons) 4. Reduction of the share of incinerated and recycled waste in the total amount of generated waste (up to 22% in 2020). Sustainable development goal 12 has not been achieved. 5. Increase in the volume of waste removed to specially designated places by 81,2%. 6. Growth of accumulated waste during operation at waste disposal sites by 25%. 7. Changes in the sectoral structure of generated waste, an increase in the share of the extractive industry (up to 84.6%) and the processing industry (up to 11,3%). 8. Growth trend of total investment in waste management (by 87%), specific investment per 1 ton of waste (by 23,8%).	1. Continuation of the negative trend of growth of generated waste at the expense of "waste of war". 2. Reducing the productivity of responsible waste management by waste 3. Further reduction of the share of incinerated and disposed waste 4. Changes in the sectoral structure of generated waste, growth in the share of construction waste, other "waste of war" 5. Clogging of land with waste (about UAH 425 billion)	1. Stopping the growth trend of generated waste, slowing down the rate of increase in GDP waste capacity 2. Initiation of growth trend indicators of GDP waste productivity in constant prices 3. Increasing the share of incinerated and disposed waste 4. Changes in the sectoral structure of generated waste 5. Growth of investments in the field of waste management in accordance with the principles of the circular economy and the European Green Course.
Low (1,77) Level of responsible waste management	Low (0,5-1,0)	Below average (2,1-2,5)

Source: Developed based on a comprehensive assessment of responsible waste management. ** Expected (possible) trends.

During the war period, in the field of waste management, the continuation of the negative trend of the reduction of GDP productivity by waste and the growth of generated waste, primarily due to the so-called "waste of war", is likely. The latter include unexploded shells, their fragments, mutilated and burned equipment, building ruins and parts of military equipment (Omelchuk & Sadogurska, 2022). In the prewar period, construction waste made up the main share of waste in landfills because it has a large volume, and during reconstruction or construction, much such waste remains. The issue of "waste of war" is complicated by the unsolved problems of landfills; during the war period, garbage accumulates in forests or forest strips (Omelchuk & Sadogurska, 2022). According to the assessment of the State Environmental Inspection, the amount of damage from land pollution with waste for the period 24.02.2022 - 26.10.2022 amounted to approximately UAH 425 billion.

In the postwar period, slowing the negative growth trend in the volume of generated waste and the waste intensity of GDP in the country depends on investment and institutional support for the development of the field of waste management on the basis of the circular economy and the European Green Course. In this direction, it is important to implement norms and standards for circular production, the national waste management system, the creation of a regional network of production facilities for the processing and disposal of industrial and household waste, and the production of equipment and machinery for waste processing (Kindzerskyi, 2022). The implementation of measures for the transition to zero pollution and the circular economy in accordance with the goals of the European Green Course and the reconstruction of the waste management infrastructure provided by the Recovery Plan of Ukraine in the direction of "Environmental safety and effective waste management" will create the prerequisites for increasing the level of waste in this area from a low to (0,5-1,0) to medium low (2,1-2,5).

The developed methodological recommendations make it possible to assess the impact of state policy on the state of the waste management sphere to adjust the composition of measures and mechanisms for the implementation of state policy based on the results of a comprehensive assessment, ensuring its effectiveness and feedback between the subject and the object of management.

4.3. Modeling the balance of network interactions in a circular ecosystem

In the circular economy, the cycle is closed, and "waste" is transformed into new products. Due to the growing need for sustainable solutions, business structures increasingly use open innovation, which is based on the principles of the circular economy, particularly the principles of recycling, recovery or repurposing. Collaboration with all stakeholders will be critical to the effectiveness of circular interaction. A circular ecosystem is a network of organizations that collaborate to create an enabling environment for collective circular transformation (Tang et al., 2022).

The basis of the network system is a set of network interactions, which are built based on the following principles:

• voluntariness, that is, the freedom to choose partnership relations to achieve the goals of each participant in the interaction, as well as the selected common goals and receive mutual benefits from cooperation;
• prioritization of connections, relying on relevant institutions to solve public administration issues;
• The collegiality of decision-making for choosing the development vector of both the network system and each participant of such a system;
• congruence/coherence of actions based on the mechanisms of agreement of decisions, actions and nature of relations between network partners;
• structuring activities and division of responsibilities to maximize the effectiveness and efficiency of processes.

The network system created in its development goes through stages characterized by the corresponding mission, strategy, technological level of products, type of organizational architecture, personnel competence, etc. Development is the basis of the transition to a higher level, for which there is a maturity model (technological, project, process, organizational, etc.). In the digital economy, the key success factor is the openness of the business, its ability to share its values and take from the market what can add value to the business, relying on cooperation with various players. At the heart of this engagement is an organization closely linked to suppliers, logistics partners and technologies that ensure the circularity of materials supported by concerned consumers and policy (Salvador R., et al., 2021). Circular ecosystems include relationships with customers, suppliers, partners and integrators. Circulation has tangible business value, and the architecting of stakeholder relationships makes much sense because it creates real change at a systemic level.

Circular ecosystems are believed to act as precursors to achieving large-scale impacts. For example, large-scale business goals (building a collection infrastructure for product returns or creating a reliable alternative to supply chains to support the industry's transition to cyclical business models) are too large for any single company. Therefore, to unlock the full potential of the circular economy, it is necessary to engage the wider ecosystem of a company or industry, collaborating both in its direct value chain and with competitors to move its entire sector or industry forward. Network interaction in the circular economy has its own specifics and is related to the implementation of tasks related to the implementation of multidirectional projects and ensuring the implementation of sustainable development goals—improving people's lives.

The network system is a graph $G(N, E)$, where $N = \{1,2, \dots, n\}$ is the set of vertices (agents) and E is the set of edges reflecting the interactions of agents (Figure 9).

A condition for the effective functioning of a network system is its network maturity. This state the network system acquires over time, provided that the goals and strategies of the network participants are consistent. The readiness for network interaction determines the nature of the effectiveness of future network systems. According to the Global Connectivity Index, Ukraine ranks 50th among 79 countries in the world. The Global Connectivity Index measures performance across 40 indicators to track the impact of information and communication technologies (ICT) on national economies, digital competitiveness and future growth.

Figure 9 Scheme of the circular ecosystem: network interaction of partners in the implementation of circular economy projects.

A characteristic feature of network interaction is the potential opportunity for each of the participants in the organizational system to act as a center or an agent or simultaneously both as a center and as an agent (when interacting with different participants). The following factors are important for determining the nature of network interactions: awareness, communication and coordination. The following approaches to qualitative assessment of the network system are distinguished: structural, resource, normative, and dynamic.

In the structural approach, all network members are represented as a graph vertex, which reflects their influence on the configuration of edges and other network members. The shape of the network and the intensity of interactions (weight of edges) are important. When forming a network system, for example, a territorial community, within which participants actively interact, it is necessary to differentiate the network based on the behavior and nature of connections between vertices.

In the resource approach, participants' opportunities to attract individual and network resources to achieve certain goals are considered, with the differentiation of participants who are in identical structural positions of the network in terms of resource potential. Using the resource potential of network participants will help to significantly improve the quality of defining the goals and tasks of clustering and classification.

A normative approach is important for the formation of trust between participants, as well as norms, rules and sanctions that affect the behavior of network participants during the implementation of processes to ensure their interaction and its consequences. Modeling the nature and degree of impacts, their distribution, etc., is important here.

The dynamic approach reflects changes in the network structure over time: the composition of network participants, the types of connections, the nature of interaction, and the structure of networks as a whole and in individual communities. It is important to identify patterns and the nature of long-term changes in the network, the nature of configurations in the network, and their development.

Decision-making is based on the concept of balance (Nash, 1953).

When forming a network system of a circular ecosystem, each of the participants has his own strategy and vision of profit from participating in the network. If the main strategy is taken as a basis—sustainable development (economic, ecological and social goals)—then it can be assumed that the choice of strategy is related to improving the quality of one's own functioning precisely according to these three components: $x_i \in X_i \in R^{n_t}$, $x_i \in X_i \subseteq R^{n_i}$; that is, each participant considers his winnings as follows:

$$x = (x_1, x_2, x_3) \in X_1 \times X_2 \times X_3 = X \in R^3, x = (x_1, x_2, x_3) \in X_1 \times X_2 \times X_3 = X \subseteq R^3.$$

Balance (Nash, 1953) $(x^e, f^e = \big(f_1(x^e)\big), f_2(x^e), f_3(x^e))) \in X \in R^3$ is defined as:

$$\begin{gathered} f_1(x^e) \max_{x_1 \in X} f_1(x_1, x_2^e, x_3^e) \\ f_2(x^e) \max_{x_2 \in X_2} f_2(x_1^e, x_2, x_3^e) \qquad (1) \\ f_3(x^e) \max_{x_3 \in X_3} f_3(x_1^e, x_2^e, x_3) \end{gathered}$$

As seen from (1), the control system of each individual agent strives to achieve its own goals, which is a completely natural phenomenon in the absence of interaction and common interests. Equilibrium is possible only under the condition of changing the strategy of all participants in the formation of a network system based on the interaction of interests and goals. The equilibrium in the interaction of agents $(x^B, f^B = (f_1(x^B)), f_2(x^B), f_3(x^B))) \in X \in R^3$ is defined as follows (Berge, 1954):

$$f_1(x^B) \max_{(x_2, x_3) \in X_2 \times X_3} f_1(x_1^B, x_2, x_3^e)$$

$$f_2(x^B) \max_{(x_1, x_3) \in X_1 \times X_3} f_2(x_1, x_2^B, x_3) \qquad (2)$$

$$f_3(x^B) \max_{(x_1, x_2) \in X_1 \times X_2} f_3(x_1, x_2, x_3^B)$$

As seen in (2), when forming a network system, each player (control system) strives to increase the profit functions of the other two, that is, to improve the quality of their functioning. In the situation of equilibrium (2), the characteristics of individual rationality are not followed, and the winnings of players in some situations exceed the situation of equilibrium (1). In this sense, network interaction has additional tangible effects on all participants of the interaction.

Network analysis uses an indicator that reflects the degree of closeness of positions between different actors in the network. In addition to determining the functional and role positions of network participants, the circle of actors who have access to resources important for the network through external contacts is also determined, which is of strategic importance for increasing the effectiveness and efficiency of the network structure. The network is heterogeneous if it consists of a large number of participants involved in multiple interstructural contacts, which expands the vision and understanding of the problem and ensures the involvement of new valuable resources.

The task of each i-th player is to choose such a strategy $x_i \in X_i$, which would allow one to achieve the greatest possible gain values $f_i(x, y)$. At the same time, each of the players must take into account the implementation of any previously unforeseeable uncertainty y ∈ Y.

The business structures of territorial communities, authorities, public organizations, and the population become participants in the network system of the circular ecosystem. Business structures are the main source of resources. To create a model of a network system of a circular ecosystem for the implementation of projects, two variables are used for business entities and for municipal authorities:

$\mathrm{E}(t)$ – the number of participants in the network system in time period t;

$G(t)$ – resources of municipal authorities, which are directed to the formation and maintenance of a favorable configuration of the network system of the circular ecosystem.

For resources directed by the authorities to the formation and maintenance of the network system (G), the following equation is used:

$$G = \lambda_0(\mathrm{E}) \left(1 - \frac{E}{l}\right) g\mathrm{E} \qquad (3)$$

λ_0 - tax rate of income of business structures taking into account environmental tax benefits (relative value);

g - average specific costs for maintaining a favorable business environment per business structure (value units).

There is a certain threshold value for each territorial community l_{max}, which is determined by the resource potential of the territory. Accordingly, function $l\,(G)$ can be represented as follows:

$$l\,(G) = l_0 \left(1 + s\frac{G}{g_0 + G}\right) \qquad (4)$$

l_0 – the business of undertaking, for the mind of the presence of an unprimed pozarinkovy vtruchannya from the side of the authorities of the state power (single);

S – the maximum possible increase in the number of business structures with positive profitability l and no external resources (visible value);

g_0 – ostentatious, which points to those l deposits in G (visible growth l with increased G from zero to g_0 maximum value $S/2$).

A parametric model for the development of a merging system based on the formation of a friendly business environment is as follows:

$$\begin{cases} E = wE\left(1 - \dfrac{E}{l(G)}\right) \\ G = E\left(1 - \dfrac{E}{l(G)}\right) l\mathrm{E} \\ l\,(G) = 1 + s\dfrac{G}{g_0 + G} \end{cases} \qquad (5)$$

The model will provide the opportunity to explore the parameters of the framing system of the circular ecosystem. We should accept the adoption of rational managerial solutions to maximize the efficiency and effectiveness of diligent minds for the development of the framing system so that the future will ensure the growth of efficiency of management with inputs.

5. Discussion

The recovery plan of Ukraine in the area of "Environmental safety and effective waste management" for the second half of 2022 provides for the adoption of key legislative acts in the field of improving environmental safety and the creation of the necessary legal conditions for the elimination of environmental threats, in particular, the development of bylaws for the implementation of the Law of Ukraine "On waste management". Adopted on June 20, 2022 (entering into force on July 9, 2023), this Law defines the legal, organizational, and economic principles of activities related to the prevention of generation, reduction of waste volumes, reduction of negative consequences of waste management activities, and promotion of preparation of waste for reuse, recycling and recovery to prevent their negative impact on human health and the natural environment.

The "polluter pays" principle assumes that the generator or owner of waste covers the costs of preventing the generation of waste and its collection, transportation and treatment, including the costs of creating and maintaining waste treatment facilities. To implement the principle of creating a competitive environment in the field of waste management, economic entities, state authorities and local self-government bodies are obliged to promote the development of competition and not to commit illegal actions that negatively affect competition in the field of waste management.

Prevention of waste generation is achieved by implementing a number of measures, including (1) encouraging and supporting sustainable production and consumption of products; (2) encouraging the production and use of resource-efficient and more durable products; (3) reducing the generation of waste by implementing the best available technologies and management methods in the process of industrial production; and (4) reducing the amount of food waste generated in trade networks and households. According to Art. 4 of the Law of Ukraine "On Waste Management", economic entities, activities that produce waste, ensure compliance with the waste management hierarchy by:

1) planning and carrying out one's activities in such a way as to prevent (reduce) the generation of waste and its negative impact on human health and the surrounding natural environment during the design, production and use of products;
2) The recovery of waste, ensuring its preparation for reuse, recycling or carrying out other methods. recovery operations, including energy production;
3) Remove only those wastes that are unsuitable for technological or economic reasons, such as recycling or other waste removal operations.

The main risks of achieving environmental safety goals, including in the direction of effective waste management, are low institutional capacity; large financial needs for the implementation of measures to stimulate the reuse, recycling and disposal of waste; and the construction of infrastructure for waste management. By the end of 2022, Ukraine plans to approve the National Targeted Environmental Program for the Management of Radioactive Waste.

The regulatory and legal foundation of environmental security, laid during the war period, is designed to form a favorable institutional environment for the development of the field of waste management and a circular economy based on European experience in the postwar recovery period of Ukraine.

In the postwar period, it was expedient to implement a national waste management system, its investment and institutional support, and the creation of a regional network of facilities for the processing/disposal of industrial and household waste, which will contribute to a gradual transition to zero pollution and a circular economy in accordance with the goals of the European Green Course. Special attention should be given to the disposal and reuse of construction waste generated as a result of infrastructure destruction. In some European countries (Denmark, Germany, and the Netherlands), the requirement to use a certain percentage of products from recycled waste in new construction is regulated. Approximately 87% of construction and demolition waste is recycled in Austria. In the Netherlands, there has been a law for approximately 10 years that prohibits the transportation of construction waste that can be recycled to landfills. In other countries, when accepting waste to a landfill, official proof is required that it is not recyclable. European experience shows that construction waste can be reused not only during the restoration of damaged objects but also during the production of construction materials.

The results of this study can be compared with similar works that consider the role of EPR and the circular economy in the field of waste management.

In particular, Hossain et al. (2022) emphasized the importance of the EPR program for the development of a circular economy in the context of plastic waste management in India. The authors emphasize the need for a comprehensive approach that includes clear regulations, incentives for producers, consumer awareness campaigns, etc. These key elements are consistent with the methodology proposed in this study.

In turn, Kumar et al. (2022), in their work on sustainable waste management of electrical and electronic equipment in India, emphasize the importance of the EPR as one of the key factors contributing to the implementation of circular economy principles. The authors also emphasize the need to take into account the perspectives of different stakeholders, which is consistent with the integrated approach used in this study.

Another similar work is that of Szto and Wilson (2023), who explore the role of EPR and the circular economy in the sporting goods industry. The authors draw attention to structural and industry-specific barriers, which is consistent with the need to take into account the industry-specific features emphasized in this study.

In general, the analysis shows that the proposed methodology for a comprehensive assessment of responsible waste management and the role of the EPR program in this process are consistent with current research in this area. The use of a balanced scorecard, expert assessment, and consideration of industry specifics can serve as effective tools for implementing the principles of the circular economy and achieving sustainable development goals.

It is also worth noting that this study complements the literature with specific recommendations on the key components of successful implementation of the EPR program and circular economy, as well as an analysis of the regulatory framework in Ukraine based on European experience.

This study prompts the following discussion:

The role of EPR in the development of a circular economy.

The results of the study emphasize the importance of the EPR program as a key tool for ensuring closed production and consumption cycles, which is in line with the principles of the circular economy. This prompts a discussion of effective mechanisms for implementing EPR programs, their adaptation to different sectors of the economy, and the integration of EPR programs with other circular economy instruments.

The Sustainable Development Goals are achieved through the lens of waste management.

This study demonstrated that effective waste management based on the principles of the circular economy and the EPR program can directly contribute to the implementation of Sustainable Development Goal 12, “Responsible consumption and production”. This initiates discussions on the role of waste management in achieving other related SDGs, for example, in the context of climate change and ecosystem conservation.

Peculiarities of implementing the circular economy in transition economies.

This study examines Ukraine's experience in shaping the regulatory framework for the transition to a circular economy. This prompts a discussion of the specific challenges and opportunities that developing countries face in implementing circular economy principles compared to developed economies.

Interaction between formal and informal waste management sectors.

This paper emphasizes the need to integrate the formal and informal waste management sectors to ensure the effectiveness of the system. It initiates discussions on the mechanisms of such integration and the distribution of roles and responsibilities between different actors.

A comprehensive approach to assessing the responsible waste management sector.

The methodology for a comprehensive assessment of waste management based on the balanced scorecard proposed in this study can serve as a basis for discussions on the development of effective indicators and analytical tools for monitoring progress in implementing the circular economy.

In general, this study lays the groundwork for a wide range of discussions on key aspects of the transition to a circular economy and the achievement of sustainable development goals through the prism of effective waste management.

6. Conclusion

The implementation of EPR and circular economy principles is of key importance for ensuring sustainable development in Ukraine. The results of the study indicate the need for a comprehensive approach to the implementation of these concepts.

A comprehensive assessment of the responsible waste management sector in Ukraine revealed negative trends, such as an increase in waste volume, a decrease in productivity indicators, and a failure to achieve target levels of recycling and disposal. This indicates the inefficiency of the existing waste management system and points to the need for systemic transformations.

During 2015–2020, the amount of generated waste of classes I–IV increased by 48.1%, the waste capacity of GDP increased by 38%, and the indicator of waste productivity of GDP at constant prices decreased by 27.2%. The share of incinerated and recycled waste in the total amount of generated waste decreased from 30% to 22%, falling short of the 2025 target (45%). In the prewar period, the volume of waste removed to specially designated places (by 81.2%) and accumulated during operation at waste disposal sites increased (by 25%). In the sectoral structure of generated waste in 2020, 84.6% fell into the extractive industry, and 11.3% fell into the processing industry. The highest level of sectoral waste productivity of gross added value is characteristic of the agricultural sector and energy supply, and the lowest is the most waste-intensive extractive sector. In 2020, the amount of investment per ton of generated waste reached UAH 30,5, increasing by 23,8%; the growth of total investments in the field of waste management amounted to 87%. At the same time, there is an intersectoral imbalance between the volumes of generated waste and capital investments in this area, which is evidence of a violation of the "polluter pays" state policy principle.

Based on the comprehensive assessment results, the experts assessed the level of responsible waste management as low. During the war period, as a result of the reduction in the volume of production, the amount of generated waste will decrease; on the other hand, the amount of "war waste" will increase. In the postwar period, slowing the negative growth trend in the volume of generated waste and the waste intensity of GDP in the country depends on investment and institutional support for the development of the field of waste management on the basis of the circular economy and the European Green

Course. In this direction, it is important to implement norms and standards for circular production, the national waste management system, the creation of a regional network of production facilities for the processing and disposal of industrial and household waste, and the production of waste processing equipment. Under such conditions, the status of responsible waste management can increase from low to low-medium.

The implementation of EPR and circular economy principles can become a key driver of the necessary changes. EPR will encourage manufacturers to develop more environmentally friendly and recyclable products and to develop waste collection and recycling infrastructure. The implementation of the circular economy concept in Ukraine requires a comprehensive approach that includes clear legislative regulation, developed infrastructure, financial and nonfinancial incentives for producers, public awareness campaigns, and the integration of the formal and informal waste management sectors.

To ensure the effective transition of Ukraine to a sustainable circular economy, it is necessary to implement a number of key recommendations. In particular, to introduce an effective EPR system with clear goals, indicators and mechanisms; develop infrastructure for waste collection, sorting, processing and disposal; ensure the coherence of the legal framework and policies in the field of waste management, environmental taxation and incentives for "green" business; intensify work to raise awareness and involve all stakeholders; and develop scientific research and innovative solutions in the field of circular economy.

Comprehensive implementation of such measures will facilitate Ukraine's transition to a sustainable circular economy model, reduce waste volumes, and mitigate the negative impact on the environment. This, in turn, will strengthen Ukraine's contribution to the Sustainable Development Goals.

The scientific novelty of the present study lies in the development of a methodological framework for a comprehensive assessment of the responsible waste management sector, the identification of key trends in the implementation of sustainable development goals through the prism of waste management, and the modeling of the equilibrium network interaction of the circular ecosystem. Further research should aim to deepen the study of EPR implementation mechanisms, the specifics of circular economy implementation in transformational economies, and the assessment of socioeconomic and environmental effects of the transition to a sustainable development model.

Ethical considerations

Not applicable.

Conflict of Interest

The authors declare no conflicts of interest.

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References

Abreu, M.C.S. de, Ceglia, D. (2018). On the implementation of a circular economy: the role of institutional capacity-building through industrial symbiosis. *Resources, Conservation and Recycling*. 138, 99-109. https://doi.org/10.1016/j.resconrec.2018.07.001

Ajwani-Ramchandani, R., & Bhattacharya, S. (2022). Moving towards a circular economy model through I4.0 to accomplish the SDGs. Cleaner and Responsible Consumption, 7, 100084. https://doi.org/10.1016/j.clrc.2022.100084

Asante, R., Faibil, D., Agyemang, M., & Khan, S. A. (2022). Life cycle stage practices and strategies for circular economy: Assessment in construction and demolition industry of an emerging economy. *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-022-21470-w

Baars, J., Domenech, T., Bleischwitz, R., Melin, H. E., & Heidrich, O. (2021). Circular economy strategies for electric vehicle batteries reduce reliance on raw materials. *Nature Sustainability*, *4*(1), 71–79. https://doi.org/10.1038/s41893-020-00607-0

Barros, M.V., Salvador, R., do Prado, G.F., de Francisco, A.C., Piekarski, C.M. (2021). Circular economy as a driver to sustainable businesses. *Cleaner Environmental Systems*, 2, 100006. https://doi.org/10.1016/j.cesys.2020.100006

Berge, C. (1954). Sur une convexité régulière non linéaire et ses applications à la théorie des jeux Bulletin de la S. M. F. 82. 301-315. https://doi.org/10.24033/bsmf.1451

Bondarenko, S., Halachenko, O., Shmorgun, L., Volokhova, I., Khomutenko, A. & Krainov, V. (2021). The Effectiveness of Network Systems in Providing Project Maturity of Public Management. *TEM Journal*, 10(1), 358-367, https://doi.org/10.18421/TEM101-45

Cabinet of Ministers of Ukraine. (2020). The concept of implementation of state policy in the sphere of promoting the development of socially responsible business in Ukraine for the period until 2030. Approved by the order of the Cabinet of Ministers of Ukraine, dated January 24, 2020, № 66. *Zakon Rada*. https://zakon.rada.gov.ua/laws/show/66-2020-%D1%80#Text

Campbell-Johnston, K., Calisto Friant, M., Thapa, K., Lakerveld, D., & Vermeulen, W. J. V. (2020). How circular is your tyre: Experiences with extended producer responsibility from a circular economy perspective. *Journal of Cleaner Production*, 270. https://doi.org/10.1016/j.jclepro.2020.122042

Campbell-Johnston, K., de Munck, M., Vermeulen, W. J. V., & Backes, C. (2021). Future perspectives on the role of extended producer responsibility within a circular economy: A Delphi study using the case of the Netherlands. *Business Strategy and the Environment*, *30*(8), 4054–4067. https://doi.org/10.1002/bse.2856

Carayannis, E. G. Bart, T.D., & Campbell D.F.J. (2012). The quintuple helix innovation model: global warning as a challenge and driver for innovation. *Journal of Innovation and Entrepreneurship*, 1(1), 1-12. https://doi.org/10.1186/2192-5372-1-2

Chambers, J. C., Allen, C. R. & Cushman, S. A. (2019). Operationalizing Ecological Resilience Concepts for Managing Species and Ecosystems at Risk. *Frontiers in Ecology and Evolution*, 7(241). https://doi.org/10.3389/fevo.2019.00241

Chenavaz, R. Y., & Dimitrov, S. (2024). From waste to wealth: Policies to promote the circular economy. Journal of Cleaner Production, 443, 141086. https://doi.org/10.1016/j.jclepro.2024.141086

Circular Economy Forum Austria. (n.d.). *Circular Economy Forum Austria*. https://www.circulareconomyforum.at/

D'Amico, G., Arbolino, R., Shi, L., Yigitcanlar, T., Ioppolo, G. (2021). Digital Technologies for Urban Metabolism Efficiency: Lessons from Urban Agenda Partnership on Circular Economy. *Sustainability*, *13*, 6043. https://doi.org/10.3390/su13116043

Diaz, A., Reyes, T., & Baumgartner, R. J. (2022). Implementing circular economy strategies during product development. *Resources, Conservation and Recycling*, *184*. https://doi.org/10.1016/j.resconrec.2022.106344

Draft plan for the recovery of Ukraine. (2022). *Materials of the working group "Environmental safety"*. The National Council for the Recovery of Ukraine from the Consequences of the War. https://www.kmu.gov.ua/storage/app/sites/1/recoveryrada/ua/environmental-safety-assembly.pdf

EkoZagroza: Official resource of the Ministry of Environmental Protection and Natural Resources of Ukraine. https://ecozagroza.gov.ua/

European Commission. (2020). *Strategic Research and Innovation Partnership on Circular Economy*. Smart Specialization Platform Slovenia. https://s3platform.jrc.ec.europa.eu/en/w/strategic-research-and-innovation-partnership-on-circular-economy

Extended producer responsibility. OECD. https://www.oecd.org/env/tools-evaluation/extendedproducerresponsibility.htm

Faibil, D., Asante, R., Agyemang, M., Addaney, M., & Baah, C. (2022). Extended producer responsibility in developing economies: Assessment of promoting factors through retail electronic firms for sustainable e-waste management. *Waste Management and Research*. https://doi.org/10.1177/0734242X221105433

Filyppova, S., Kovtunenko, Y., Filippov, V., Voloshchuk, L., & Malin, O. (2021). Sustainable development entrepreneurship formation: system-integrated management tools. E3S Web of Conferences, 255, 01049. https://doi.org/10.1051/e3sconf/202125501049

Focus.Day dedicated to the circular economy and energy transition (2022). https://ceosforfuture.at/2022/10/06/focus-day-im-zeichen-der-kreislaufwirtschaft-und-energiewende/ [in German]

Geissdoerfer, M., Savaget, P., Bocken, N.M.P., Hultink, E.J. (2017). The Circular Economy – A new sustainability paradigm? *Journal of Cleaner Production*, 10, 757-468. https://doi.org/10.1016/j.jclepro.2016.12.048

Gong, Y., Xie, S., Arunachalam, D., Duan, J., & Luo, J. (2022). Blockchain-based recycling and its impact on recycling performance: A network theory perspective. Business Strategy and the Environment, 31(8), 3717-3741. https://doi.org/10.1002/bse.3028

Gui, L. (2020). Recycling infrastructure development under extended producer responsibility in developing economies. *Production and Operations Management*, *29*(8), 1858–1877. https://doi.org/10.1111/poms.13202

Hemidat, S., Achouri, O., El Fels, L, Elagroudy, S., Hafidi, M., Chaouki, B., Ahmed, M., Hodgkinson, I., Guo, J. (2022). Solid Waste Management in the Context of a Circular Economy in the MENA Region. *Sustainability*, *14*, 480. https://doi.org/10.3390/su14010480

Hossain, R., Islam, M. T., Shanker, R., Hossain, S. M. Z., Dhodapkar, R., & Sahajwalla, V. (2022). Plastic Waste Management in India: Challenges, Opportunities, and Roadmap for Circular Economy. Sustainability, 14(8), 4425. https://doi.org/10.3390/su14084425

Hossain, R., Islam, M.T., Shanker, R., Hossain, S.M.Z., Dhodapkar, R., & Sahajwalla, V. (2022). Plastic Waste Management in India: Challenges, Opportunities, and Roadmap for Circular Economy. Sustainability, 14(8), 4425. https://doi.org/10.3390/su14084425

Ibn-Mohammed, T., Mustapha, K. B., Godsell, J., Adamu, Z., Babatunde, K. A., Akintade, D. D., Acquaye, A., Fujii, H., Ndiaye, M. M., Yamoah, F. A., & Koh, S. C. L. (2021). A critical review of the impacts of COVID-19 on the global economy and ecosystems and opportunities for circular economy strategies. *Resources, Conservation and Recycling*, *164*.. https://doi.org/10.1016/j.resconrec.2020.105169

Islam, M. T., Iyer-Raniga, U., & Trewick, S. (2022). Recycling Perspectives of Circular Business Models: A Review. Recycling, 7(5), 79. https://doi.org/10.1002/sd.2796

Jacobides, M. G., Cennamo, C., Gawer, A. (2018). Towards a theory of ecosystems. *Strategic Management Journal*, 39, 2255–2276. https://doi.org/10.1002/smj.2904

Johnson, E. (2022). Closing competency gaps for circularity: Exploring partner dynamics for circular-oriented innovation. Sustainable Production and Consumption, 34, 130-147. https://doi.org/10.1016/j.spc.2022.08.029

Joltreau, E. (2022). Extended producer responsibility, packaging waste reduction and eco-design. *Environmental and Resource Economics*. https://doi.org/10.1007/s10640-022-00696-9

Kindzerskyi, Y. (2022). Post-war restoration of Ukrainian industry: challenges and policy features. *Economic analysis*, 32(2), 101-115. https://doi.org/10.35774/econa2022.02.101

Korhonen, J., Nuur, C., Feldmann, A., Birkie, S E. (2018) Circular economy as an essentially contested concept. *Journal of Cleaner Production*, 175(544), 552 https://doi.org/10.1016/j.jclepro.2017.12.111

Kumar, A., Gaur, D., Liu, Y., & Sharma, D. (2022). Sustainable waste electrical and electronic equipment management guide in emerging economies context: A structural model approach. Journal of Cleaner Production, 336, 130391. https://doi.org/10.1016/j.jclepro.2022.130391

Kumar, A., Gaur, D., Liu, Y., & Sharma, D. (2022). Sustainable waste electrical and electronic equipment management guide in emerging economies context: A structural model approach. Journal of Cleaner Production, 336, 130391. https://doi.org/10.1016/j.jclepro.2022.130391

Kunz, N., Mayers, K., & Van Wassenhove, L. N. (2018). Stakeholder views on extended producer responsibility and the circular economy. *California Management Review*, *60*(3), 45–70. https://doi.org/10.1177/0008125617752694

Mandpe, A., Paliya, S., Gedam, VV., Patel, S., Tyagi, L., Kumar, S. (2022). Circular economy approach for sustainable solid waste management: A developing economy perspective. *Waste Management & Research*. https://doi.org/10.1177/0734242X221126718

Ministry of Economic Development and Trade of Ukraine. (2016). *Report on green transformation in Ukraine based on OECD "green" growth indicators*. https://www.green-economies-eap.org/resources/2016_GreenTransformation%20in%20Ukraine%20ENG.pdf.

Ministry of Economic Development and Trade of Ukraine. (2017). *Sustainable Development Goals: Ukraine. National report*. https://www.sd4ua.org/wp-content/uploads/2017/10/SDG-leaflet-engl_F-1.pdf.

Moore, J.F. (1993). Predators and prey: a new ecology of competition. *Harvard Business Review*, 71 (3), 75-86. http://www.ncbi.nlm.nih.gov/pubmed/10126156

Morales, M.E.. Batlles-delaFuente, A.. Cortés-García, F.J.. Belmonte-Ureña, L.J. (2021). Theoretical Research on Circular Economy and Sustainability Trade-Offs and Synergies. *Sustainability* , *13*(21), 11636; https://doi.org/10.3390/su132111636

Nash, J.F. (1953). Two Person Cooperative Games. Econometrica. 21. 128–140. https://doi.org/0012-9682(195301)21:1<128:TCG>2.0.CO;2-N

National Council for the Reconstruction of Ukraine from the Consequences of War. (2022). *Draft plan for the recovery of Ukraine. Materials of the working group "Environmental safety"*. https://www.kmu.gov.ua/storage/app/sites/1/recoveryrada/ua/environmental-safety-assembly.pdf.

Negrete-Cardoso, M., Rosano-Ortega, G., Álvarez-Aros, E.L. et al. (2022). Circular economy strategy and waste management: a bibliometric analysis in its contribution to sustainable development, toward a post-COVID-19 era. *Environmental Science and Pollution Research*, 29, 61729–61746. https://doi.org/10.1007/s11356-022-18703-3

OECD. (2024). Extended producer responsibility. https://www.oecd.org/env/tools-evaluation/extendedproducerresponsibility.htm.

Official website of the State Statistics Service of Ukraine. http://www.ukrstat.gov.ua/

State Statistics Service of Ukraine. *Official website*. http://www.ukrstat.gov.ua/.

Omelchuk, O., Sadogurska, S. (2022). Nature and War: How Russia's Military Invasion Affects Ukraine's Environment. https://ecoaction.org.ua/pryroda-ta-vijna.html [in Ukrainian]

On waste management: Law of Ukraine dated June 20, 2022 № 2320-IX. Entry into force 09.07.2023. https://zakon.rada.gov.ua/laws/show/2320-20#Text [in Ukrainian]

Pandey, K. P., Jha, U. R., Kushwaha, J., Meshram, S. U., & Dhoble, A. S. (2023). Practical ways to recycle plastic: current status and future aspects. Journal of Material Cycles and Waste Management, 25(3), 1249-1266. https://doi.org/10.1007/s10163-023-01611-0

Petit-Boix, A., Apul, D., Wiedmann, T., & Leipold, S. (2022). Transdisciplinary resource monitoring is essential to prioritize circular economy strategies in cities. *Environmental Research Letters*, *17*(2). https://doi.org/10.1088/1748-9326/ac44c6

Popadyuk O.V. (2018). Scientific and practical principles of evaluating the system of social responsibility of business at the enterprise. *Economic space*, 130, 177-187. [in Ukrainian]

Rahmani, M., Gui, L., & Atasu, A. (2021). The implications of recycling technology choice on extended producer responsibility. *Production and Operations Management*, *30*(2), 522– 542. https://doi.org/10.1111/poms.13279

Reike. D.,Vermeulen. W. J.V., Witjes. S. (2017). The circular economy: New or Refurbished as CE 3.0? — Exploring Controversies in the Conceptualization of the Circular Economy through a Focus on History and Resource Value Retention Options. *Resources, Conservation and Recycling*, 135, 246-264. https://doi.org/10.1016/j.resconrec.2017.08.027

Report on green transformation in Ukraine based on OECD "green" growth indicators (2016). Ministry of Economic Development and Trade of Ukraine, 60.

Rizos, V. & Bryhn, J. (2022). Implementation of circular economy approaches in the electrical and electronic equipment (EEE) sector: Barriers, enablers and policy insights. *Journal of Cleaner Production*, 338, 130617. https://doi.org/10.1016/j.jclepro.2022.130617

Rubio, S., Ramos, T. R. P., Leitão, M. M. R., & Barbosa-Povoa, A. P. (2019). Effectiveness of extended producer responsibility policies implementation: The case of Portuguese and Spanish packaging waste systems. *Journal of Cleaner Production*, *210*, 217–230. https://doi.org/10.1016/j.jclepro.2018.10.299

Saarinen, A., Aarikka-Stenroos, L. (2022). Financing-Related Drivers and Barriers for Circular Economy Business: Developing a Conceptual Model from a Field Study. *Circular Economy and Sustainability*, 2(3). https://doi.org/10.1007/s43615-022-00222-5

Salvador, R., Barros, M. V., Freire, F., Halog, A., Piekarski, C. M., & De Francisco, A. C. (2021). Circular economy strategies on business modelling: Identifying the greatest influences. *Journal of Cleaner Production*, *299*. https://doi.org/10.1016/j.jclepro.2021.126918

Silva, F.C., Shibao, F.Y., Kruglianskas, I., Barbieri, J.C. & Sinisgalli, P.A.A. (2019). Circular economy: analysis of the implementation of practices in the Brazilian network. *Revista de Gestão*, 26(10), 39-60. https://doi.org/10.1108/REGE-03-2018-0044

Steenmans, K., & Ulfbeck, V. (2023). Fostering the circular economy through private law: Perspectives from the extended producer responsibility concept. Resources, Conservation and Recycling, 195, 107016. https://doi.org/10.1016/j.resconrec.2023.107016

Strategic Research and Innovation Partnership on Circular Economy (2020). Slovenia: Smart Specialisation Platform. https://s3platform.jrc.ec.europa.eu/en/w/strategic-research-and-innovation-partnership-on-circular-economy

Stratiychuk V. (2022). Peculiarities of social responsibility assessment in strategic enterprise management. Socially responsible business conduct is a component of sustainable development: a collection of materials based on the results of the All-Ukrainian competition of scientific papers. In general ed. Ustymenko V.A. Kyiv, 25-36. [in Ukrainian]

Stuchtey, M.R. & Kranendijk, S. (2018). The Role of Business in the Circular Economy. Markets, Processes and Enabling Policies. *Report of a CEPS Task Force*. file:///C:/Users/Admin/Downloads/RoleBusinessCircularEconomyTFR.pdf

Sustainable Development Goals: Ukraine (2017). National report. *Ministry of Economic Development and Trade of Ukraine, 176. https://www.sd4ua.org/wp-content/uploads/2017/10/SDG-leaflet-engl_F-1.pdf*

Sustainable Development Strategy for Ukraine by 2030 (2017). https://www.undp.org/ukraine/publications/sustainable-development-strategy-ukraine-2030

Szto, C., & Wilson, B. (2023). Reduce, re-use, re-ride: Bike waste and moving towards a circular economy for sporting goods. International Review for the Sociology of Sport, 58(6), 911-931. https://doi.org/10.1177/10126902221138033

Szto, C., & Wilson, B. (2023). Reduce, re-use, re-ride: Bike waste and moving towards a circular economy for sporting goods. International Review for the Sociology of Sport, 58(6), 911-931. https://doi.org/10.1177/10126902221138033

Tamasiga, P., Miri, T., Onyeaka, H., Hart, A. (2022). Food Waste and Circular Economy: Challenges and Opportunities. *Sustainability*, *14*, 9896. https://doi.org/10.3390/su14169896

Tang, Y. M., Chau, K. Y., Fatima, A., & Waqas, M. (2022). Industry 4.0 technology and circular economy practices: Business management strategies for environmental sustainability. *Environmental Science and Pollution Research*, *29*(33), 49752–49769. https://doi.org/10.1007/s11356-022-19081-6

The concept of implementation of state policy in the sphere of promoting the development of socially responsible business in Ukraine for the period until 2030. Approved by the order of the Cabinet of Ministers of Ukraine, dated January 24, 2020, № 66. https://zakon.rada.gov.ua/laws/show/66-2020-%D1%80#Text [in Ukrainian]

The European Green Course: opportunities and threats for Ukraine: an analytical document. (2020). Under the editorship N. Andrusevich. Kyiv: Resource-Analytical Center "Society and Environment", 75. https://www.rac.org.ua/uploads/content/571/files/european-green-dealuafinal.pdf [in Ukrainian]

UNDP (2017). *Sustainable Development Strategy for Ukraine by 2030*. https://www.undp.org/ukraine/publications/sustainable-development-strategy-ukraine-2030.

Vernier, J. (2021). Extended producer responsibility (EPR) in France. *Field Actions Science Report*, Special Issue 23, 22–25. http://journals.openedition.org/factsreports/6557

Waste and resource management: a brief description of EU directives and their implementation schedule (2014). Kyiv, 9. http://www.if.gov.ua/files/uploads

Waste of war: what it is and how to deal with it? https://rubryka.com/article/waste-from-war/ [in Ukrainian]

Yang, X., Li, Q., Wu, M., & Zhou, Y. (2022). Circular economy in European Union textile industry chain and key issues of waste textiles treatment. Fangzhi Xuebao. *Journal of Textile Research*, 43(1), 106-112. https://doi.org/10.13475/j.fzxb.20210804507

Zavhorodnii, A., Ohiienko, M., Biletska, Y., Bondarenko, S., Duiunova, T. & Bodenchuk, L. (2021). Digitization of agribusiness in the development of foreign economic relations of the region. *Journal of Information Technology Management*, Special Issue, 123-141. doi: 10.22059/JITM.2021.82613

Zerkina, O., Nikishyna, O., Bondarenko, S., Makovoz, O., & Durbalova, N. (2022). Institutional support for formation of reproductive logistics on the bread and bakery market of Ukraine. *Agricultural and Resource Economics*, 8(3), 153–177. https://doi.org/10.51599/are.2022.08.03.08