

## Waste management in the circular economy: Status and challenges in Ukraine

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**Abstract.** During the study, the goal was achieved, namely, to assess the current state of the waste management system in Ukraine and to develop recommendations for its improvement based on the principles of a circular economy. Methods of analysis and synthesis were employed to examine the problem, enabling the evaluation of the theoretical foundations of the circular economy and the principles of waste management. The method of statistical analysis was used to collect and analyse empirical data, while the modelling method was employed to predict possible scenarios for the development of waste management by 2025. The results of the study demonstrated that Ukraine's economy remains largely dependent on a linear model, characterised by the creation of products without consideration for further processing. This is confirmed by the increase in the waste intensity of gross domestic product (GDP), which indicates the absence of significant changes in the adoption of resource-efficient technologies. The stable share of recycled and incinerated waste (20%-25%) against the background of an increase in the total volume of generated waste indicates a lack of changes in waste management technologies and policies, as well as an underdeveloped recycling infrastructure. The growth in the volume of generated waste per unit of GDP demonstrates a tendency towards reduced resource efficiency in the economy, while the number of waste management infrastructure facilities has concurrently declined. The methodological approach described in the research ensures transparency of the research process, thereby allowing it to be replicated using similar methods and data sources

**Keywords:** circularity; closed loop; resources; reuse; waste disposal; waste management

### Introduction

The relevance of this study arises from the need to analyse the current state of waste management in Ukraine within the context of a circular economy (CE), and to identify the main challenges and prospects for implementing innovative approaches. Waste management in the context of a CE is one of the key topics in modern environmental research. The CE, or closed-loop economy, involves the recovery, reuse, and rational consumption of resources, which creates additional value through new services and intelligent solutions. At the global level, the problem of waste management remains pressing. According to research, about 2.12 billion tonnes of waste are generated annually worldwide, with 99% of purchased goods being disposed of within

six months. Despite the growing attention to the concept of a CE, its actual implementation has decreased: only 7.2% of the global economy is circular, which is 21% lower than five years ago (Cherry, 2024). In Ukraine, the situation regarding waste management is also a cause for concern. In 2017, the government approved the National Waste Management Strategy until 2030, which envisages the implementation of a systemic approach to waste management at the national and regional levels, reducing waste generation by increasing recycling and reuse (Cabinet of Ministers of Ukraine, 2017). According to the Ministry of Environmental Protection and Natural Resources of Ukraine, the waste management system requires improvement to comply with

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EU standards and integrate into the European waste management system (Ministry of Environmental Protection and Natural Resources of Ukraine, 2022).

Research by scientists and practitioners highlighted the modernisation of approaches to the waste management system within the circular economy. M.T. Munir *et al.* (2023) explored the key components of effective solid waste management, various available machine learning tools, their strengths and weaknesses, and how they can be utilised to create effective waste management systems. In addition, the authors examined the challenges associated with using machine learning for skilled solid waste management and detailed the current and future trends in this field. According to the researchers, the ability of machine learning algorithms to process large amounts of data and detect patterns and trends can be highly valuable for various tasks, such as forecasting, anomaly detection, and optimisation. R.E.V. Sesay & F. Ping (2025) examined AI-driven sorting technologies in municipal waste management as a transformative foundation for sustainable municipal solid waste management (MSWM), focusing on waste reduction, resource recovery, and the development of closed-loop systems. According to these researchers, the application of advanced technologies such as artificial intelligence (AI), machine learning, and big data analytics offers transformative opportunities for enhancing CE frameworks in MSWM. AI-driven solutions can optimise waste collection routes, predict waste generation patterns, and improve sorting efficiency at recycling facilities. Machine learning algorithms can identify trends in waste composition and inform adaptive management strategies, while big data analytics provide comprehensive insights into resource flows and system inefficiencies. These technologies can synergistically enhance decision-making, minimise waste generation, and maximise resource recovery.

According to K. Das *et al.* (2025), the application of Internet of Things (IoT) technologies and big data analytics for the real-time management of agri-food waste is a major challenge in the agri-food sector. The authors highlighted the positive impact of IoT and big data in combating agri-food waste; at the same time, they provide practical suggestions for key players across the supply chain. A. Bratovic (2024) identified microplastics as a persistent anthropogenic pollutant that has become a global problem due to their widespread distribution and unknown threat to the environment and living organisms. This research focused on the removal of plastic fragments through photocatalytic reactions using recently developed photocatalytic composites, as well as the mechanism of photocatalytic degradation of microplastics. The study by S. Sultana *et al.* (2021) aimed to assess awareness and practices regarding solid waste management among people living in the community. Solid waste management represents a serious public health problem and is closely related to the daily lives of individuals. According to the authors, members of the community can play a key role in solid waste management. According to D. Chester *et al.* (2021), the principal barrier

to acquiring and deploying viable waste-to-energy (WTE) technologies in remote or deployed expeditionary sites is the high capital, operating, and maintenance costs. The authors' calculated economic impacts confirm that open burning of waste is not only hazardous to humans and the environment, but also not economically viable. Considering the economic impacts and the mitigation of human and environmental health risks, WTE technologies could be a viable waste management strategy for the future. This study aimed to analyse the current state of the waste management system in Ukraine and to develop recommendations for its improvement based on the principles of the CE.

## Materials and Methods

The research process employed a systematic approach that allowed for a comprehensive assessment of the current state of waste management in Ukraine in the context of a circular economy. The research methodology included several stages aimed at achieving the stated goal and obtaining new scientific results. Methods of analysis and synthesis were used to analyse the problem, enabling an assessment of the theoretical foundations of the circular economy and the principles of waste management. A critical review of scientific and theoretical sources was conducted, including recent publications in leading international journals over the past three to five years, as well as regulatory and legal documents of Ukraine in the field of waste management (Munir *et al.*, 2023; Horbal & Slipachyk, 2023; Sesay & Ping, 2025). This provided a solid basis for determining the relevance of the problem and identifying existing scientific approaches. Specifically, the study by S. Sultana *et al.* (2021) aimed to assess awareness and practices regarding solid waste management among people living in the Mugda community of Dhaka, using a descriptive correlational research design.

The method of statistical analysis was used to collect and analyse empirical data. The data sources included official reports of the State Statistics Service of Ukraine (Goal 12..., n.d.), the Ministry of Environmental Protection and Natural Resources of Ukraine (Waste management, n.d.), as well as analytical reports of international organisations (Waste generation in Europe, n.d.). To study and analyse trends in the waste management system, estimated indicators such as GDP waste intensity, the share of incinerated and recycled waste in the total volume of generated waste, the volume of generated waste per unit of GDP (kg per 1,000 USD), the number of waste treatment plants, their capacity by type of plant, and the number and volume of landfills for waste disposal (storage) were used. In the field of waste management, the dynamics of financing, both capital and current, were also analysed.

The processing of these materials enabled the assessment of changes in the field of waste management and the identification of major development trends. The modelling method was used to predict possible scenarios for the development of waste management until 2025. Average rates of change in the number of facilities and their capacity, as

well as the level of reduction in the residual volume of landfills for household waste disposal, were taken into account. This approach enabled the assessment of the potential impact of the implementation of a circular economy on the environmental and economic situation in the country. The methodological approach described in this study ensures transparency of the research process, allowing it to be replicated using similar methods and data sources. In addition, it enabled the production of scientifically sound results that can inform the development of recommendations for the implementation of a circular economy at the regional level.

## Results and Discussion

Despite the fact that Ukraine ranks confidently among the top ten countries in the world in terms of the volume of accumulated waste, the country recycles, according to various sources, only between four and eight per cent, taking into account sorting and incineration (Garbage recycling, 2024). With the signing of the Association Agreement between Ukraine and the EU, Ukraine entered a new stage of waste management, and Directive 2008/98/EC of the European Parliament and of the Council (2008), which formed the basis of the National Waste Management Strategy, also became an obligation for Ukraine (Resolution of the Cabinet of Ministers of Ukraine No. 820-p, 2017). The EU Waste Management Directive (Directive 2008/98/EC of the European Parliament and of the Council, 2008) defines five key levels of the waste hierarchy, with priority given to the first three stages. Waste prevention is the most effective approach in the context of a circular economy, as it reduces the negative impact on the environment at the production and consumption stages. Minimising resource use, eco-design, and extending the life cycle of products help reduce waste before it is generated. Preparing for reuse involves repairing, refurbishing, and repurposing products, preventing them from becoming waste. This helps to reduce the consumption of primary resources, save energy, and lower greenhouse gas emissions. Recycling or reusing waste aims to transform it into secondary raw materials that can be reused in production processes. This approach reduces the need for the extraction of natural resources and helps to reduce environmental pollution.

The first three levels of the waste management hierarchy are consistent with the principles of sustainable development and the circular economy, as they minimise the impact on the environment and human health, reduce waste management costs, preserve natural resources, and contribute to the creation of new business models, jobs, and economic growth. The remaining levels of the hierarchy are considered lower priorities. Alternative recycling, particularly energy recovery, involves incinerating waste to produce energy. Although this process allows for the extraction of energy value, it is accompanied by emissions of harmful substances and the loss of material resources. Final disposal of waste by landfill represents the worst management option, as landfills occupy large areas, pose risks to soil, water, and air pollution, and contribute to the

formation of greenhouse gases. Consequently, the EU and most countries worldwide have directed their environmental policies towards prioritising the first three approaches, thereby promoting the rational use of resources and reducing negative impacts on nature (Dovgal *et al.*, 2024).

Waste can be prevented through conscious consumption by purchasing only necessary items in sufficient quantities. A mandatory component of the remaining tasks is the provision of high-quality equipment for the collection, transportation, storage, and recycling system. Since the Industrial Revolution, products have been consumed in largely the same way: companies extract or harvest resources to create a product that consumers then buy, use, and ultimately discard. This model is known as the linear model of mass consumption. However, this model has contributed to changes in the climate that, if left unaddressed, threaten to make life significantly more difficult in the coming decades. Every year, about 2.6 trillion USD worth of materials in fast-moving consumer goods – representing 80 per cent of the material value – are thrown away and never recovered (Gatzer *et al.*, 2022). An alternative to the linear model is the CE. In a closed-loop economy, resources can be used repeatedly, often for the same or similar purposes.

The CE is governed by three main principles:

1. Preserving and enhancing natural capital (the world's stock of natural assets) by controlling finite resources and balancing the flow of renewable resources.
2. Optimising resource output by ensuring that products, components, and materials are recycled at the highest possible level at all times.
3. Increasing system efficiency and eliminating unintended negative impacts, such as air and water pollution.

A CE is a worthy goal in itself, but it also offers organisations a competitive advantage. One McKinsey study estimates that the CE could generate over 1 trillion USD in revenue in Europe alone by 2050 (Bouton *et al.*, 2016). Another McKinsey analysis suggests that transitioning to closed-loop business models could help European consumer goods companies access up to 500 billion EUR in value by 2030 (Gatzer *et al.*, 2022). Companies, especially consumer goods firms, that commit to environmental, social, and governance (ESG) metrics are likely to become the leaders of the future.

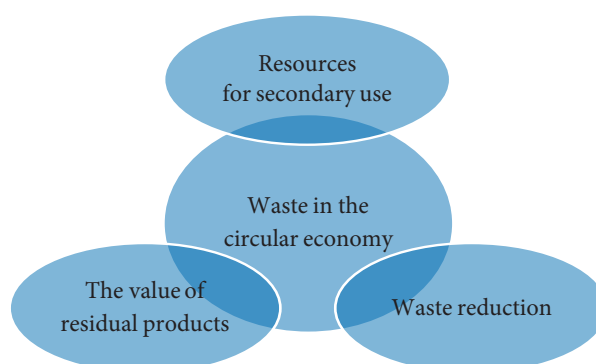
At the national level, productivity can mean the difference between a good standard of living and a poor one. For a company, productivity can determine whether it can afford to raise employees' wages, or even whether it can continue operating. Stagnant or declining productivity can signal serious trouble ahead for individuals, organisations, and nations alike. To reduce the enormous volume of waste currently produced by societies, emissions-intensive production activities must be dramatically slowed. In the past, the idea of slowing productivity growth might have been shocking to governments and consumer goods companies alike. The question now is how consumer goods companies can survive in a world where shoppers are purchasing fewer new items. The clear business potential of

closed-loop consumer goods models offers an answer to this question. Consumer goods companies should regard circularity as an opportunity, not a threat; closed-loop business models can forge a valuable connection between business logic and sustainability. Growing consumer demand for environmentally friendly products is arguably the greatest driver of circularity, but other factors will also play a role. These include regulation, technological progress, infrastructure, supply-side activities, and the macroeconomic environment.

It is worth beginning with regulation. Some governments are already promoting circularity. As part of the European Green Deal, the European Union has adopted the Circular Economy Action Plan (CEAP), which commits billions of euros towards achieving net-zero emissions by 2032. Several European countries have also introduced extended producer responsibility schemes, providing significant financial incentives for companies that aim to transition to closed-loop business models (Freundt *et al.*, 2024). However, regulation, as well as companies' efforts to move towards more sustainable business models, can be significantly influenced by the macroeconomic environment. An economic downturn, inflation, or geopolitical instability can make organisations more reluctant to invest in

closed-loop business models. Similarly, a recession can drive consumers towards secondary markets for recycled products. As evidenced by analyses of trends in global society, particularly in Europe, there is a significant opportunity for consumer goods organisations across different sectors to adapt their business models to exploit the profitable opportunities of the circular economy (Frey *et al.*, 2023).

Circularity refers to practices that optimise resource use and minimise waste throughout the entire production and consumption cycle, emphasising sustainability and cost-effectiveness (Bouton *et al.*, 2016). The only way to create these two realities – reducing the carbon footprint and generating profit – is to establish a closed-loop economy. For the past 200 years, the economy has operated built linearly: material is extracted, transformed, produced into goods, sold, consumed, and ultimately discarded as waste. Society has dealt poorly with waste and has largely ignored the consequences (McKinsey Center for Business and Environment, 2015). In the CE system, waste is not considered a final product, but a resource that can be reintegrated into the production and economic cycle. The CE seeks to reduce waste generation, maximise its utilisation, and transform it into resources that generate added value. The role of waste in the circular economy is illustrated in Figure 1.



**Figure 1.** The role of waste in a circular economy

**Source:** created by the author

In a circular economy, waste is transformed into a valuable resource for secondary use, becoming raw material for new products. For example, plastic is processed into pellets, which are then used in the production of new goods, and organic waste is utilised to produce compost or biogas. Waste reduction is achieved through eco-design, multi-level recycling, and product reuse. Instead of landfilling waste, energy or materials can be recovered from it; for example, construction waste is employed in road construction. It is important to clearly define and implement the stages of waste management on a sustainable basis, thereby contributing to the efficient use of resources and reducing the negative impact on the environment.

Priority for reuse involves extending the life cycle of products by repairing, upgrading, recycling, or reusing materials. For instance, in the textile industry, companies such as Patagonia actively employ the concept of reuse,

offering customers the opportunity to repair old clothing and purchase second-hand items (Product Repair, n.d.). In the automotive sector, Renault is implementing the Refactory programme, aimed at repairing and reusing car parts, thereby reducing the need for new materials (The Refactory..., n.d.). An important aspect is the development of effective infrastructure for the collection and sorting of waste, which ensures the possibility of its reuse in production. For example, TerraCycle specialises in recycling waste that is traditionally non-recyclable (e.g., toothbrushes, cosmetic packaging, etc.) (The TerraCycle Difference, n.d.). In the plastics sector, Loop Industries (n.d.) is developing technologies for recycling plastic waste, transforming it into high-quality material for new products.

Residual waste that cannot be recycled can be used for energy production. For example, the Swedish company Fortum uses the incineration of municipal waste to

generate electricity and heat, thereby providing heating for cities (Circular economy, n.d.). As the final stage in the circular economy system, the safe disposal of waste involves minimising environmental impact. For instance, Veolia is developing innovative methods for the safe disposal of toxic waste, including the use of isolated landfills and chemical stabilisation of hazardous substances (We are committed to..., n.d.).

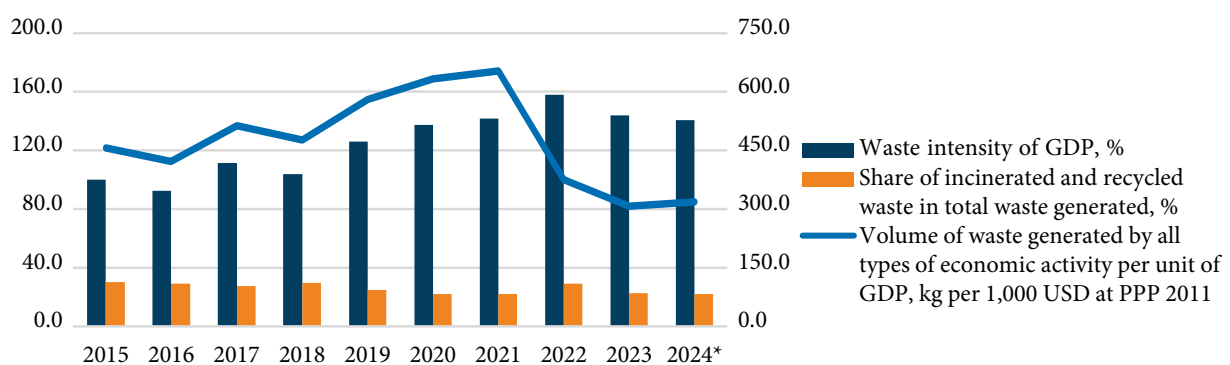
The integration of waste into the circular economy system offers several advantages. Firstly, there are economic benefits, such as reducing the cost of purchasing primary materials, the development of new business models such as leasing and remanufacturing, and the creation of additional market opportunities. Secondly, environmental sustainability is promoted by reducing CO<sub>2</sub> emissions through decreased waste incineration and extraction of natural resources, alongside reducing environmental pollution, for example, diminishing the quantity of plastic waste in the world's oceans. Thirdly, there are social benefits, including the creation of new jobs in recycling and eco-design sectors, as well as enhancing public awareness of the responsible use of resources.

To ensure the functioning of the waste management system, following European legislation, the activities of specialised enterprises covering the various stages of waste management are necessary. Such enterprises may have different work profiles depending on the type of waste and its treatment methods. A separate group consists of enterprises that collect mixed waste, deliver it to landfills, and subsequently sort it. Organic waste can be used to produce biogas or compost, whilst inorganic waste is pressed, crushed, and sent to processing plants for the manufacture of various equipment and consumer goods. In Ukraine, such enterprises have been created based on solid waste landfills near Lviv, Kropyvnytskyi, and Kharkiv, and there is also a waste recycling line in the Chernivtsi Region. In addition, two plants operate in the Zakarpattia Region, two in Vinnytsia, and one each in Kharkiv and Cherkasy (Garbage recycling..., 2024). Some enterprises accept pre-sorted secondary raw materials by individual categories. They operate through reception points or through agreements with

building owners who install specially marked containers for sorting. Such points operate in every city and a significant number of villages, contributing to the expansion of the practice of secondary material use.

Another type of enterprise is engaged exclusively in waste sorting, selecting equipment according to its capabilities. The sorted raw materials are sold to processing plants for further use in production processes. There are approximately 30 such sorting stations in Ukraine (Garbage recycling..., 2024). In addition, a separate category consists of enterprises that directly process secondary raw materials. In Ukraine, about 20 plants specialise in the processing of waste paper, about 30 specialise in glass containers, and about 40 specialise in plastics. Often, the same enterprises that previously operated as reception and sorting points also engage in recycling (Garbage recycling..., 2024). Thus, effective waste management and its integration into the circular economy system not only minimises the negative impact on the environment but also contributes to economic development and the promotion of social responsibility.

Recycling companies purchase waste paper, plastic, and cullet from outside Ukraine due to the low percentage of domestic sorting, whilst some European countries achieve over 90% waste recycling rates (Dolzhenkova, 2023). The experience of European and other countries in the field of waste management can be utilised to organise waste-free production and significantly reduce waste at the national level. Even before the full-scale invasion, 51 MW of biogas capacity had been created in different regions of Ukraine based on landfills and agricultural waste – more than 30 installations. The first stage of the world's largest biogas plant has been opened in the Vinnytsia Region. However, this does not solve the problem of waste accumulation in general – waste volumes are not decreasing, and it is not economically viable to incinerate it all. Instead, the processing of sorted waste, which becomes secondary raw material, is highly effective (Garbage recycling..., 2024). The gross domestic product (GDP) waste intensity indicator illustrates the share of waste in the creation of GDP. As shown in Figure 2, waste intensity increased gradually from 2015 (approximately 100%) to 2024 (approximately 141%).



**Figure 2.** Main parameters of waste generation and disposal in Ukraine, 2015-2024

**Note:** \* – preliminary data

**Source:** calculated by the author based on data from I. Werner (2024), Goal 12: Responsible consumption and production (n.d.)

In 2022, the waste intensity of GDP reached its highest value (158.2%), indicating an increase in waste generation relative to economic growth. In 2023, the figure decreased to 143.7%, and the forecast for 2024 is 140.9%. This may indicate a stabilisation of the situation and the implementation of certain measures to optimise waste management. The main reasons for the increase can be identified as:

a) an increase in the volume of economic activity, which is accompanied by greater waste generation;

b) a possible rise in the share of sectors of the economy with high waste intensity, such as industry or construction.

The data indicate a significant waste intensity within the Ukrainian economy, which has fluctuated in recent years but shows a tendency to gradually decrease. This may be a consequence of changes in the structure of production caused by military operations in Ukraine. The growth of this indicator suggests that the country's economy remains largely dependent on a linear model – the creation of products without consideration for recycling. This presents a challenge for the transition to a CE.

The indicator of the share of incinerated and recycled waste in the total volume of waste generated demonstrates the efficiency of waste recycling and disposal processes. The data in Figure 2 shows that the share has remained almost stable at 20%-25% throughout the years. Among the main factors causing such “stability” are the lack of significant changes in waste management policies or technologies, and possibly insufficient motivation for enterprises or an underdeveloped recycling infrastructure. With the growth of the total volume of waste, this stable share implies that the absolute amount of non-recycled waste is also increasing. This situation highlights the need to introduce innovative waste recycling and disposal technologies.

Another analysed indicator – the volume of waste generated per unit of GDP (kg per 1,000 USD) – reflects how much waste is generated in creating a certain volume of GDP, that is, it serves as an indicator of resource efficiency. As the analysis data (Fig. 2) shows, the indicator increased from 2015 (approximately 450 kg) to 2021 (approximately 650 kg). Among the main reasons for this growth are the decline (or absence) of resource-efficient

technologies, as well as a decrease in the share of high-tech, less resource-intensive industries. The economy is gradually losing its resource efficiency, which once again underlines the relevance of transitioning towards the principles of sustainable development. The growth of specific waste volumes indicates a decline in the potential for integrating the principles of a circular economy, creating an additional burden on both the environment and the economic system.

One of the key signals of this process is the increase in the waste intensity of GDP, which demonstrates growing environmental pressure. To reduce this indicator, it is necessary to implement measures aimed at transitioning to cleaner technologies, encouraging enterprises to use secondary resources, and developing eco-design and more efficient production processes. However, without a comprehensive state policy and investments in relevant innovations, it will be difficult to change the situation. An additional problem remains the low share of recycled waste, which currently amounts to only about 20%. This situation requires active investment in the development of waste recycling infrastructure, the introduction of effective mechanisms to support companies engaged in the secondary use of materials, as well as the strengthening of state regulation in the field of waste management. The lack of appropriate policies and financing threatens further waste accumulation and an increased negative impact on ecosystems.

The negative trend in the growth of waste per unit of GDP indicates a gradual deterioration of production processes, which poses a threat to future economic development. This indicator should be used as one of the key criteria for assessing the impact of the circular economy and the effectiveness of environmental initiatives. Its monitoring and analysis will enable a timely response to problems and the adjustment of sustainable development strategies aimed at optimising resource use and minimising waste. In order to confirm the relevance and necessity of implementing the principles and elements of the CE, it is necessary to analyse several other important indicators, namely: the number of waste processing plants, their capacity by type of plant, and the number and volume of landfills for waste disposal (storage) – Table 1.

**Table 1.** Number of waste treatment facilities and landfills for waste disposal (as at the end of the year)

	Number, units				Installed capacity, thousand tonnes				Residual capacity, million m <sup>3</sup>			
	2021	2022	2023	2024*	2021	2022	2023	2024*	2021	2022	2023	2024*
Total number of waste treatment facilities	546	546	413	388	20,015.2	9,079.6	6,384.2	4,841.7	–	–	–	–
for waste incineration to produce energy or material products	304	264	239	221	1,186.1	1,106.0	1,321.8	1,278.1	–	–	–	–
for waste incineration for the purpose of heat treatment of waste	88	71	59	53	112.8	72.8	82.9	81.0	–	–	–	–
for waste recovery	251	191	110	95	12,779.6	7,885.7	4,977.8	4,107.5	–	–	–	–

	Number, units				Installed capacity, thousand tonnes				Residual capacity, million m <sup>3</sup>			
	2021	2022	2023	2024*	2021	2022	2023	2024*	2021	2022	2023	2024*
other waste treatment facilities for permanent storage and disposal of waste	20	20	5	3	15.1	15.1	1.7	1.0	-	-	-	-
Landfills for waste disposal, total	1,688	1,453	1,331	1,217	-	-	-	-	3,809.0	4,083.6	3,895.9	3,359.7
of which, household waste	778	794	791	787	-	-	-	-	160.3	147.2	156.4	154.3

**Note:** data exclude the temporarily occupied territory of the Autonomous Republic of Crimea, the city of Sevastopol, and parts of the temporarily occupied territories in the Donetsk and Luhansk regions; \* – preliminary data

**Source:** calculated by the author based on I. Werner (2024), Goal 12: Responsible consumption and production (n.d.)

The number of waste treatment plants decreased by 28.9% over the period 2021-2024. The largest decrease occurred among waste recovery plants (-62%). There is a decline in plants for the incineration of waste for energy use (-27%) and for incineration without energy production (-40%). The number of other plants for the permanent storage and disposal of waste has decreased particularly significantly (-85%). The total installed capacity of waste treatment plants decreased (-75.8%). The largest drop in capacity occurred at waste recovery plants (-67.8%). At the same time, the capacity of waste incineration plants increased in 2023, but decreased again in 2024. The total number of landfills is gradually decreasing (-28%). Despite this, the residual volume of landfills does not show a stable decrease. It first increased in 2022 and then decreased in 2024. The number of landfills for household waste has hardly changed, and their residual volume remains high.

The analysis revealed a general negative trend in the reduction of waste treatment facilities, which contradicts the principles of the circular economy. The decline in waste recovery is particularly noticeable, which may indicate insufficient funding, technological lag, or weak state policy supporting the recycling industry. At the same time, the number of landfills for waste disposal is gradually decreasing, but their residual volume does not show a sustainable reduction. This may mean that a significant proportion of waste continues to accumulate in existing landfills rather than being effectively recycled or disposed of.

A positive aspect is the effort to increase the efficiency of waste incineration, particularly for energy production,

but the total capacity of such facilities fluctuates, which may indicate unstable operation or limited resources. It is important to accelerate the modernisation of processing facilities and introduce technologies that reduce dependence on landfills. Special attention should be paid to the use of automated sorting systems based on artificial intelligence, as well as the creation of incentives for businesses engaged in the recycling and reuse of materials. It is important to consider the fact that military operations are being conducted on the territory of Ukraine, and that the data provided excludes the temporarily occupied territory of the Autonomous Republic of Crimea, the city of Sevastopol, and parts of the temporarily occupied territories in the Donetsk and Luhansk regions. Thus, the analysis of the above indicators allows the following conclusions to be drawn:

1. The reduction in the number of waste treatment facilities and landfills may indicate optimisation of the waste management system, as well as transitions to other forms of utilisation or a reduction in waste generation.
2. The largest reduction concerns waste recovery facilities, which is a negative signal, as this is a key component of the CE.
3. A slight increase in the residual volume of landfills in 2022 may be associated with the reconfiguration of landfills or more efficient waste management.

Based on the trends described in Table 1, quantitative forecasts can be made regarding changes by 2025 (Table 2). To do this, the average rates of change in the number of facilities and capacity, as well as the reduction in the residual volume of landfills, will be taken into account.

**Table 2.** Forecast of key indicators for 2025 (summarised)

Indicator	2023	2024 (forecast)	2025 (forecast)
Number of treatment plants	413	330	260
Capacity of plants (thousand tonnes)	6,384.2	4,788	3,590
Number of landfills for disposal	1,331	1,130	960
Residual volume of landfills (million m <sup>3</sup> )	3,895.9	3,820	3,740
Number of municipal waste landfills	791	690	600
Residual volume of municipal waste	156.4	150	145

**Source:** author's calculations

The calculations show that there is a trend towards infrastructure reduction: the number of facilities and landfills is decreasing, which may lead to an increase in the burden on residual facilities or the need to introduce new technologies. Capacity decline: If waste treatment capacity continues to decline at this rate, it may cause problems with processing significant volumes of waste, especially in densely populated regions. Need for modernisation: Investments are needed in modern waste recovery facilities, as they show the greatest reduction in both volume and capacity. The main recommendations for effective waste management and the development of a circular economy are to introduce new recycling technologies, improve the efficiency of existing facilities, and encourage the reuse of materials. One of the key areas is the development of waste disposal technologies that will reduce dependence on landfills. This requires supporting scientific research in the field of materials recycling, introducing new mechanical and chemical methods of waste treatment, and encouraging businesses to invest in innovative approaches.

An important aspect is the modernisation of existing recycling plants and the expansion of their capacity. The use of automated sorting systems based on artificial intelligence and machine learning technologies can significantly increase the efficiency of this process. For example, sorting robots are used in Sweden and the Netherlands that use computer vision to recognise and separate materials in the waste stream. Such technologies increase the accuracy and speed of sorting, reducing the amount of residual waste and improving the quality of secondary raw materials.

Encouraging recycling and the reuse of materials also plays an important role in reducing waste. Effective tools may include tax incentives for companies that implement environmentally friendly production cycles or subsidies for small businesses that use secondary raw materials. In Germany and Austria, a system of “green certificates” is

in place, which encourages enterprises to use secondary materials, contributing to the formation of an environmentally responsible business environment. In addition, it is necessary to conduct an analysis of the environmental efficiency of landfills and gradually reduce their number, replacing them with modern waste processing and disposal complexes. The experience of Singapore and South Korea demonstrates that the creation of centralised processing complexes that combine mechanical sorting, chemical recovery, and energy production can significantly reduce the amount of waste entering landfills. Thus, the development of innovative technologies, the application of artificial intelligence in sorting and recycling, as well as support for businesses in implementing environmentally responsible approaches, can significantly increase the efficiency of waste management and contribute to the development of a circular economy.

As the results of the analysis shown in Table 3 indicate, during the period 2010-2024, the volume of capital investments in the waste management sector increased by 7.2 times. However, it is necessary to note the uneven dynamics, with sharp fluctuations. The share of capital investments in total investments in environmental protection changed unevenly, with peaks in 2019 and 2022. There was an average increase in the share for 2010-2024, which indicates a gradual reorientation of capital investments specifically towards waste management. Current expenses during the period 2010-2024 increased by 4.6 times. The dynamics are relatively stable, with an average annual increase of approximately 6%-8%. In 2022, there was a decrease due to martial law in Ukraine; however, in 2023, expenses returned to the level of 2021. The share of current expenditures in total environmental protection expenditures increased by 12.1% over the period 2010-2024. Between 2015 and 2024, the share stabilised at 36%-40%, indicating a continued focus on current waste management expenditures.

**Table 3.** Dynamics of expenses in the field of “waste management” in Ukraine

Indicator name	Years									Rate of change, %
	2010	2015	2018	2019	2020	2021	2022	2023	2024*	
Capital investments, at current prices, million UAH	475.6	737.5	1,182.1	5,754.3	2,899.8	3,719.6	2,795.9	3,204.6	3,428.1	7.2 times
Share in the total amount of capital investments in environmental protection, %	17.2	9.6	11.7	35.4	21.9	26.4	43.4	38.7	33.5	+16.3
Current expenses, at current prices, million UAH	2,599.6	6,801.9	8,830.2	10,227.1	11,197.2	11,501.1	8,963.5	11,310.0	12,028.5	4.6 times
Share in the total amount of current expenses for environmental protection, %	25.1	40.2	36.3	37.2	40.0	37.5	37.2	38.6	37.2	+12.1

**Note:** \* – preliminary data

**Source:** calculated by the author based on data from I. Werner (2024), Goal 12: Responsible consumption and production (n.d.)

Based on the average rate of change in recent years (2020-2024: +10% annually), it is possible to forecast the volume of capital investments in 2025 to be approximately 3,876 million UAH. However, taking into account external factors (martial law, limited funding), growth may slow down. The share of capital investments in total investments in environmental protection, assuming the upward trend continues (albeit with possible fluctuations), will be approximately 42%-45% in 2025. The forecast for the volume of current expenses (assuming stable growth with an average annual increase of 6%-8%) can be outlined within the following limits for 2025: about 13,150 million UAH. At the same time, the share of current expenditures in total environmental protection expenditures is expected to stabilise at 38%-40%, unless there are drastic changes in state policy.

The results of the analysis allow the following conclusions to be drawn:

1. In the field of waste management, there is a positive dynamic in the increase in funding, both capital and current, which indicates an increase in attention to environmental issues.
2. The largest increase in capital investments occurred in 2019; however, there has since been stable, moderate growth.
3. Current expenditures have remained stable, even under wartime conditions, which indicates their importance for supporting the main processes in the field of waste management.
4. In 2025-2026, an increase in funding can be expected, although external factors (war, economic situation) may slow the pace.

It should be noted that, as a result of military operations in Ukraine, a significant amount of demolition waste has been generated. As of April 2024, according to the Ministry of Community, Territorial and Infrastructure Development of Ukraine, the volume of such waste exceeded 223 thousand tonnes. In particular, more than 189 thousand tonnes were recorded in Kyiv Region, more than 6 thousand tonnes in Mykolaiv Region, and about 1.9 thousand tons in Odesa Region (Consequences of the war..., 2024). In April 2024, the Ministry of Environmental Protection and Natural Resources of Ukraine reported that the total volume of demolition waste across the country exceeded 670 thousand tonnes (Since the beginning..., 2023). It is worth noting that official statistics may not account for some waste remaining at the sites of its generation and not subject to formal recording. In addition, due to martial law, the State Statistics Service of Ukraine has limited the publication of detailed data on waste generation and treatment (Churikanova, 2020). Given the limited availability of official information, accurate data on the volume of waste related to military operations may be incomplete. However, the available figures indicate the scale of the problem and the need for effective management of such waste to minimise its negative impact on the environment and public health.

Studies highlighting the importance of implementing innovative approaches to waste management support the

hypothesis that new technologies are needed in this process. As noted by N. Cherry (2024), the use of artificial intelligence to optimise business models and improve infrastructure is an important factor in the transition to a circular economy. These results are consistent with this conclusion, as the implementation of automated sorting and recycling systems increases the efficiency of waste management and reduces waste volume. S.A. Bandh *et al.* (2025) argued that waste management and the circular economy are two of the most important concepts contributing to sustainable approaches to environmental protection. The adoption of these principles contributes to the creation of a more sustainable future for current and future generations. According to H. Richter (2024), projects aimed at cleaning polluted water bodies using floating systems made of recycled materials have demonstrated effectiveness in reducing pollution and reusing resources. It is appropriate to agree with this approach, as it is consistent with the principles of a circular economy; however, research showed that the implementation of such technologies requires significant investment and government support.

It fully supported the idea that the CE paradigm can also be extended by using the waste management sector to transform waste into resources. In comparison with previous studies, M. Arena *et al.* (2021) attempt to outline how a waste collection and recycling system can contribute to overcoming some of the cultural, technological, regulatory, and market barriers that affect the demand and supply of recycled material. K. Kotyal (2023) also explored the main challenges and opportunities in the context of sustainable waste management, identifying key areas for improvement and innovation to facilitate the transition to a circular economy. A.S. Rosokhata & M.G. Minchenko (2023) analysed in detail the main tools of the circular economy and their application in Ukraine. The authors compared the dynamics of waste management in Ukraine and EU countries, which is consistent with the conclusions about the need to adapt European practices to improve the national waste management system. The idea proposed by A.S. Rosokhata & M.G. Minchenko (2023) on the importance of extended producer responsibility (EPR) as a key mechanism for waste minimisation deserves support. The analysis of the formation of the circular thinking paradigm during wartime conditions in Ukraine, conducted by N.I. Horbal & S.V. Slipachyk (2023) is particularly relevant in the context of this study. It is reasonable to agree with N.I. Horbal *et al.* (2021) stated that the adaptation of EU methodologies and the use of international experience can accelerate the transition to a circular economy. However, the results indicated that Ukraine needs to take into account specific economic and social features for the effective implementation of these methods.

The study by V.V. Roleders *et al.* (2024) on the conceptual foundations of the circular economy and logistics resource management models is an important addition to this analysis. The authors emphasised the importance of closed logistics chains for achieving environmental and

economic benefits. This view is supported by the assumption that integrating logistics principles into the circular economy will contribute to the creation of effective business solutions. M. Varfolomieiev & O. Churikanova (2020) considered the problems of implementing the circular economy in the global context and the possible obstacles to its implementation in Ukraine. Their study confirmed the conclusions regarding the need to form a state policy to support circular business models. The authors also emphasise the importance of involving the private sector and the public in the process of economic transformation.

The research of Ye. Mishenin & M. Vysochanska (2023) on reforming solid waste management policy in Ukraine was consistent with the conclusions regarding the need to update national legislation by European standards. In addition, the study by M.V. Ruda *et al.* (2021) showed a significant lag of Ukraine behind developed countries in the field of the circular economy, which is confirmed by the results obtained. The authors' recommendations on the need for a comprehensive approach to the implementation of the circular economy at the state level are supported. Considering traditional linear supply chains and their transformation into circular models is important for companies, consumers, and the environment (Fahrni *et al.*, 2024). The findings confirmed that the use of circular chains creates strategic advantages for businesses, reducing costs and increasing resource efficiency. Similar results were obtained in the study by T. Freundt *et al.* (2024), which demonstrated the importance of "green" marketing strategies for attracting consumers. Agreement with these findings is expressed, and it is believed that further research can help to develop effective mechanisms for stimulating the circular economy at the enterprise level. The analysis of scientific sources demonstrated a significant correlation between the results of other researchers and the findings of this study. Most studies confirmed that the implementation of a circular economy requires a comprehensive approach, involving the public and private sectors, developing innovative technologies, and adapting international experience. At the same time, the specific conditions of Ukraine require the development of individual strategies that take into account the economic, environmental, and social aspects of this process.

## Conclusions

The study achieved its goal – an analysis of the challenges and prospects for implementing a circular economy in

waste management in Ukraine was undertaken. The study showed that the main obstacles on this path are insufficient infrastructure for waste collection and processing, the economic inefficiency of certain processing technologies, and the lack of incentives for businesses to transition to a circular model. In particular, the share of incinerated and recycled waste in the total volume of waste generated remained almost stable at 20%-25% during 2015-2024, which demonstrates the absence of significant changes in waste management policies or technologies, as well as possible insufficient motivation for enterprises or the absence of a developed recycling infrastructure. The existing waste management system in Ukraine does not yet meet the principles of a circular economy, as a significant part of resources is not returned to economic circulation but ends up in landfills, which has a negative impact on the environment.

The results of the study confirmed that waste in the circular economy is of strategic importance as a source of secondary raw materials. Effective management of waste contributes to environmental sustainability, economic growth, and the reduction of the impact of human activity on the environment. To achieve these goals, it is necessary to develop a modern infrastructure for the collection, sorting, and processing of waste, introduce effective incentives for businesses, promote environmental awareness among the population, and improve the legislative framework to support the circular economy. Prospects for further research in this area may be aimed at developing mechanisms to stimulate businesses to implement circular models, conducting a detailed analysis of the economic efficiency of modern waste processing technologies at the regional level, as well as studying the best practices of European countries in integrating the principles of the circular economy into national strategies. Finding ways to adapt these solutions to the realities of Ukraine, taking into account economic, social, and environmental factors, is especially important.

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## Conflict of Interest

None.

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## Управління відходами у циркулярній економіці: стан та виклики в Україні

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**Анотація.** Під час проведення дослідження досягнуто мети, що полягала в оцінці поточного стану системи управління відходами в Україні та розробці рекомендацій щодо її вдосконалення на основі принципів циркулярної економіки. Для аналізу проблеми використовувалися методи аналізу та синтезу, що дозволило оцінити теоретичні засади циркулярної економіки та принципи управління відходами. Для збору та аналізу емпіричних даних було використано метод статистичного аналізу, для прогнозування можливих сценаріїв розвитку управління відходами до 2025 року – метод моделювання. Результати дослідження засвідчили, що економіка України значною мірою залишається залежною від лінійної моделі, що характеризується створенням продукції без урахування подальшої переробки. Це підтверджується зростанням відходоємності внутрішнього валового продукту (ВВП), яка свідчить про відсутність суттєвих змін у впровадженні ресурсоефективних технологій. Стабільна частка утилізованих та спалених відходів (20-25 %) на фоні зростання загального обсягу утворених відходів вказує на недостатність змін у технологіях та політиці поводження з відходами, а також брак розвиненої інфраструктури переробки. Це призводить до збільшення кількості неутілізованих відходів, що вимагає запровадження інноваційних технологій та підвищення мотивації для підприємств. Збільшення обсягу утворених відходів на одиницю ВВП демонструє тенденцію до зниження ресурсоефективності економіки, одночасно спостерігається скорочення кількості об'єктів інфраструктури для поводження з відходами. Позитивним аспектом є збільшення фінансування у сфері поводження з відходами, зокрема капітальних інвестицій. Попри виклики, поточні витрати залишаються стабільними навіть в умовах війни, що свідчить про розуміння важливості підтримки екологічних ініціатив. Методологічний підхід, описаний у роботі, забезпечує прозорість процесу дослідження, що дозволяє повторити його з використанням аналогічних методів і джерел даних

**Ключові слова:** циркулярність; замкнений цикл; ресурси; повторне використання; утилізація відходів; поводження з відходами