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THE CIRCULAR ECONOMY AS AN INNOVATIVE APPROACH TO FIGHTING CLIMATE CHANGE: A STATISTICAL STUDY OF ITS IMPACT ON THE SUSTAINABLE DEVELOPMENT

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ABSTRACT

The circular economy, based on principles of resource preservation, recycling, and reuse, presents an innovative solution to the challenges of climate change and sustainable development. This economic model aims to minimize waste, reduce greenhouse gas emissions, and improve the efficiency of resource use, offering significant environmental and economic benefits. It represents a shift towards a more sustainable industrial model that enhances economic efficiency while reducing environmental impact. This study analyzes the impact of circular economy practices on sustainable development in Ukraine through statistical examination of key indicators such as GDP, CO_2 emissions, waste generation and treatment, and investments in environmental protection. Special attention is given to waste management metrics, including recovery, incineration, and landfill disposal. A comparative analysis between Ukraine and EU countries explores the correlation between waste generation and economic growth, providing insights into the future development of circular practices. The authors assess the correlation between implemented circular practices and changes in economic, environmental, and social indicators to evaluate overall effectiveness in addressing climate change. Additionally, analysis of environmental expenditures highlights the practical and economic advantages of circular strategies, particularly in air and water protection. The research offers a theoretical and practical framework for understanding the circular economy's potential to reduce environmental pollution and enhance natural resource use. The findings support the circular economy's role in achieving the UN Sustainable Development Goals, particularly in mitigating climate change and preserving biodiversity. The study underscores the urgency of Ukraine's transition to a circular economy, especially amid the challenges of military aggression.

Keywords: *circular economy, climate change, sustainable development, GDP, CO2 emissions, waste generation, waste recovery, current expenditures, capital investments, environmental domain, statistical study*

1. INTRODUCTION

The circular economy, as a model of production and consumption that minimizes waste, is a key part of the philosophy of sustainable development and the green economy in general. The benefits of the circular economy include stimulating economic growth and job creation and reducing negative environmental impact and emissions. Many countries have included circular economy commitments in their national development plans and climate programs. The circular economy is a way to reduce environmental pollution and save production costs. This economy is a prerequisite for a new industrial revolution, as it helps maximize economic efficiency in industry and reduce the negative

environmental impact. Its implementation involves a set of measures aimed ultimately at the sustainable development of enterprises and society.

The concept of circular economy is becoming increasingly relevant in the context of sustainable development and environmental protection. The linear model of "extraction-production-consumption-disposal" leads to resource depletion, pollution, and waste accumulation. On the other hand, the circular economy is based on the principles of a closed cycle, where waste from one production becomes a resource for another, thus minimizing losses and negative environmental impact. For Ukraine, as a country with a resource-dependent economy, implementing the principles of circularity and zero waste production is a highly relevant and important task. Creating closed cycles of material flows, reintegrating waste into production systems and maximizing the resource value of products at all stages of their life cycle is the basis for the transition to a sustainable and eco-efficient economy in Ukraine.

In the context of Ukraine's European integration course, it is important to develop innovations and transition from a traditional linear economy to a modern circular economy model. This transition should be carried out comprehensively, per current requirements and European trends. In order to ensure competitive advantages and create favourable conditions for the development of the circular economy in Ukraine, it is necessary to conduct thorough scientific research and study the experience of developed countries in implementing this model, which will help to increase our country's competitiveness.

The purpose of this study is to assess the impact of implementing the circular economy model on achieving sustainable development in Ukraine by analyzing economic, environmental and social indicators, as well as to study the relationship between waste generation and recycling, greenhouse gas emissions, gross domestic product and investments in environmental activities. It will also substantiate the prospects and direction of further development of the circular economy in Ukraine, considering international experience and current challenges, particularly under martial law.

2.LITERATURE REVIEW

2.1 CIRCULAR ECONOMY: EVOLUTION OF THE CONCEPT AND ESSENCE OF THE ECONOMIC CATEGORY

The modern economic system requires new innovative approaches and has lost the ability to ensure sustainable development of society in the future. The category "circularity" means the efficient reuse and recycling of resources, materials and products in closed cycles.

Reike D., Vermeulen W.J.V. and Witjes S. (2018) identify three key stages in the development of the circular economy concept:

The first stage (1970-1990) focused on waste management, emphasizing waste reduction, reuse and recycling. It was during this period that the 3R concept – Reduce, Reuse, Recycle – began to take shape: 1. Reduce – to reduce the use of natural resources and increase production efficiency; 2. Reuse – to reuse products for their original purpose; 3. Recycle – to recycle materials to create new products of the same or lower quality.

The second stage (1990-2010) saw the implementation of an environmental efficiency strategy based on the idea of environmental payments. During this period, environmental problems acquired an economic dimension. In addition, the issues of ozone depletion and global warming acquire the status of global challenges, and waste-free technologies are introduced mainly in industry.

In the third stage, which lasts from the end of 2010 to the present day, the concept of the circular economy is finally taking shape. The World Economic Forum proposed and expanded the principles of the circular economy in 2018 and is currently applying the 10R model: Refuse – refusal to produce a product using an "environmentally hazardous" technology, offering another product; Rethink – rethinking the use of a product, its exchange or sharing; Repair – repair and maintenance of a defective product with its further use; Refurbish – restoration of an old product for its further consumption; Remanufacture – re-processing and use of a part of an old product in a new product; Repurpose – reorientation of a part of an old product in a new product for another purpose; Recover – burning materials to recover the energy lost in their production (World Economic Forum). Thus,

the 10-R model is less resource-intensive than the 3-R model, but much more complex and requires a clear selection and selection of raw materials at the design stage and in the design process.

During this period, along with the already recognized global problems of the second stage, new threats to the survival of humanity were also identified:

- Global population growth: according to the UN, in 2010 the population amounted to 6.96 billion people, in 2023 - 8.01 billion, and the forecast for 2050 - 8.92 billion people (World Population Prospects).
- Increased waste: according to the World Bank, waste will increase from 2.24 billion tons in 2020 to almost 3.88 billion tons by 2050 (Silpa K., Siddarth S., Sarur Ch., 2021).
- Depletion or disappearance of most natural resources: global resource extraction is projected to reach 190 billion tons by 2060, up from 143 billion tons in 2019 (United Nations Environment Programme, 2019).

Today, more than 500 global companies are implementing the concept of a circular economy.

Geissdoerfer M. at all (2017) theoretically proves that the circular economy is a regenerative system in which resource consumption, emissions and energy losses are minimized by closing and reducing material and energy cycles.

Haas W., Krausmann F., Wiedenhofer D., Heinz M. (2015) consider the circular economy as a strategy to reduce the consumption of raw materials and waste production by closing the economic and environmental loop of resource flows. Kirchherr J., Reike D., Hekkert M. (2017) define the concept of "circular economy" as an economic system based on business models that provide for alternative reuse. It is aimed at achieving sustainable development, environmental protection, economic growth and social justice in the interests of both present and future generations. The circular economy as an economic model is described by Murray A. Skene K. and Haynes K. (2015). They believe that in this model, both the results and processes of resource supply and production are planned and organized to maximize human well-being and the efficiency of ecosystems.

The circular economy model is an innovative platform that ensures sustainable development through the transition from a linear model based on consumption and disposal to a model in which the life of products is maximized, natural resources are reused, and materials and waste are minimized as much as possible. Currently, there are three distinctive circularity cycles that are gradually becoming more widespread: the closing of resource cycles, which is defined by the traditional economic system; the slowing of resource cycles and material flows through the extension and intensification of product use to maintain their value and cost over time; and the narrowing of resource cycles through the more efficient use of materials, resources and products in a linear system.

A systemic and comprehensive approach to the implementation of the circular economy can be implemented holistically, but at the same time, each regional or urban system is based on the features of the circular economy (Yatsenko, O., Shvydanenko, O., & Shvydanenko, H., 2022). We agree that the circular economy is focused on resource recovery, which determines its essence and structure.

2.2 THE INNOVATIVE ROLE OF THE CIRCULAR ECONOMY IN THE FIGHT AGAINST CLIMATE CHANGE AND IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT

Reducing greenhouse gas emissions, addressing resource depletion and environmental pollution, and optimizing waste management have become hot topics at the global level (Dantas et al. 2021; Sadhukhan et al. 2020; Zhang et al., 2019; Mahdhi & Belgaroui, 2025). Countries around the world have defined climate change mitigation efforts as a commitment to reduce emissions or implement advanced technologies to limit them (Peña et al. 2021; Serrano et al. 2021). In addition, the growth of population and living standards has led to the automation of production, which in turn has contributed to mass production and consumption, as well as to the increase in solid waste. The growing amount and complexity of waste seriously threaten the environment and human health (Chioatto and Sospiro, 2023; Kurniawan et al., 2022).

Implementing circular economy strategies is an effective tool for increasing the sustainability of the global system. It is increasingly clear that achieving structural optimization within the sustainable

development framework is impossible without using circular economy strategies (Alhawari et al., 2021). National governments are striving to decouple economic growth from the consumption of natural resources and environmental pollution while trying to preserve economic resources as long as possible (Almagtome et al., 2020; Atabaki et al., 2020). The application of circular economy principles is primarily aimed at preventing resource waste and optimizing energy and material cycles at different levels: the micro level includes businesses and consumers, the meso level includes economic agents that interact symbiotically, and the macro level includes cities, regions, and governments (Rincón-Moreno et al., 2020).

Due to the significant differences between research areas and schools of thought, Nikolaou et al. (2021) found that definitions of the circular economy emphasize both material conservation and economic growth. As a new economic development model, the circular economy requires the restructuring and modernization of the economic system by the laws governing the circulation of materials and energy flows in the natural ecological system (Shen et al., 2020). The circular economy is not limited to improving the waste management system to increase resource efficiency, reduce raw material consumption, and increase economic benefits. It is increasingly recognized as an effective strategy for policy development and for reducing environmental pollution and greenhouse gas emissions (De Pascale et al., 2021; Durán-Romero et al., 2020).

Countries worldwide have agreed to work together to mitigate the effects of climate change (Fawzy et al., 2021). One of the main goals is to reduce global warming to below 1.5 °C compared to pre-industrial levels. It also envisages a 45% reduction in carbon emissions by 2030 and achieving carbon neutrality by 2050 by the Paris Agreement, which was signed by 196 parties at the 21st Conference of the Parties (United Nations Framework Convention on Climate Change 2021). To achieve these goals, countries are implementing economic and social reforms. Additional measures include raising social awareness, implementing policies that promote climate stability, implementing sustainable urban planning, transitioning to a circular economy, supporting sustainable agriculture, developing clean transport, and conducting climate research (Moore et al., 2021).

The innovative role of the circular economy in combating climate change and in the context of sustainable development is most clearly manifested in the following areas:

1. With the growth of industrialization, the issue of climate change caused by industry is becoming increasingly urgent. Circular economy strategies help reduce carbon emissions and create profitable business models for the industry, improving quality, efficiency, and working conditions by monitoring the carbon footprint throughout the product life cycle (Khan et al., 2021). Blockchain technology in supply chains can provide accurate, real-time data on closed-economy processes such as circular design, production efficiency, and recycling, significantly reducing the carbon footprint of supply chain operations. The conversion of carbon dioxide, which contributes to global warming, into high-value-added products has become an important area of research. The authors estimate that 5–10% of carbon dioxide emissions can be converted into fuels and chemicals within the framework of a circular economy (Cucciniello and Cespi, 2018). Wang et al. (2019) found that resource recovery measures can reduce the overall carbon emissions of industrial parks by replacing carbon-intensive energy sources through a quantitative analysis of the impact of the circular economy. Therefore, it can be argued that using industrial by-products in the circular economy reduces carbon emissions and increases the value of industrial processes. Overall, the circular economy strategy can effectively reduce carbon emissions from industrial processes and help combat climate change.
2. Population growth leads to an increase in waste, the disposal of which is becoming increasingly complex and contributes to climate change. At the same time, a circular economy based on waste recycling can effectively combat climate change (Osman et al., 2022). The European Union is implementing strategies to achieve a circular economy, in particular, it plans to increase the recycling rate of municipal waste to 65% and ensure that all plastic packaging is recycled by 2030 (Aceleanu et al., 2019). Recycling and transforming waste into valuable raw materials to produce value-added goods contributes to a more efficient use of resources and a reduced carbon footprint compared to traditional disposal methods such as landfilling and

incineration. Therefore, conducting more research in large-scale recycling and implementing technologies to achieve a circular economy and combat climate change is important.

3. Global energy consumption is increasing due to improved quality of life. However, increasing energy consumption is accompanied by increased greenhouse gas emissions, which raises concerns about climate change (Nurgaliuly & Smagulova, 2025). Implementing circular economy strategies and digital technologies, including artificial intelligence, can improve energy efficiency and facilitate carbon trading, which can help countries achieve their climate change mitigation goals (Jose et al., 2020). Using a standard greenhouse gas quantification model and scenario analysis, Islam et al. (2021) found that combining circular economy principles with renewable energy can reduce greenhouse gas emissions in the livestock sector in Bangladesh by 37.5%. A circular economy strategy is well-aligned with climate change goals and serves as an effective tool to address climate change challenges. It can reduce carbon emissions in industry, waste management, energy consumption, construction and transport, which helps mitigate global climate change. In addition, circular economy strategies impact air and water quality, energy consumption, natural resource use, solid toxic waste and land use. Therefore, circular economy strategies can contribute to mitigating global climate change by increasing the use of renewable energy and transforming the energy mix into a more sustainable one.
4. The circular economy will create numerous opportunities for industrial growth and provide opportunities for optimizing the food system. A proposed circular economy path can provide a theoretical basis for the future sustainability of industry, agriculture and trade. Concentrating on the recycling, treatment, production, packaging, and marketing of waste in individual enterprise parks and developing an eco-industrial park based on a closed-loop economy can bring several benefits. For waste generated from bulk products such as construction waste, the quality and productivity of the waste are assessed, and the waste data is uploaded to the cloud, thus facilitating the trade of bulk waste. At the same time, implementing waste separation at the processing site will undoubtedly lead to long-term benefits in sustainable development.

There are opportunities to recycle construction waste and use it in new construction sites, which allows for resource conservation and carbon reduction, thus contributing to the fight against climate change. Instead of throwing away waste that hurts the climate, the focus should be reusing construction waste. The transition to a circular economy based on reuse and recycling is key to resource efficiency and climate change mitigation. Circular economy strategies are essential for combating climate change in all sectors, as they ensure the rational use of resources and reduce carbon emissions (Podlevska O., & Podlevskyi, A., 2023). It is important to focus on the entire life cycle, especially the end-of-life phase, which is critical for reuse, recovery and recycling.

The circular economy is an innovative waste management approach implemented through three main pathways: waste elimination, material recycling, and natural regeneration through ecosystems. Circular economy strategies can contribute to the creation of sustainable waste management systems that maximize economic efficiency, reduce resource consumption, and prevent environmental pollution, thus reducing the pressures faced by individual countries (Yang et al., 2023). The closed-loop economy is an important strategy for preventing waste generation through sustainable product design, using recycled materials, and reducing packaging. Implementing circular design principles, such as extending product life, encouraging reuse and repair, and increasing consumer awareness of sustainable practices, can significantly reduce waste (Nelles et al., 2016). Recycling is a key element of the circular economy, as it provides secondary raw materials for new products and highlights the importance of reducing the amount of waste going to landfills to avoid soil and groundwater pollution (Gheewala, 2014). Improving waste collection infrastructure, setting strict recycling standards, and introducing incentives for using recycled materials are necessary to increase recycling rates (Hua et al., 2024). Together, these measures contribute to sustainable development.

5. The circular economy is key to combating climate change and achieving the Sustainable Development Goals (SDGs) by significantly reducing greenhouse gas emissions (Leal Filho et al., 2024). By using practices such as reusing, repairing, recycling and remanufacturing materials, the circular economy reduces the need for new raw materials, reducing emissions associated with extraction, processing and transportation. Furthermore, by promoting the use of renewable energy sources and

increasing energy efficiency, the circular economy contributes to reducing emissions associated with energy production (Janik et al., 2020). By reducing waste and minimizing incineration and landfill, the circular economy also helps reduce emissions of methane and other greenhouse gases, which has a positive impact on air quality and, consequently, reduces the risks of respiratory and heart diseases, improving both the environment and human health (Kalebaila et al., 2024).

3.METHODOLOGY

The documents were selected for this work using the following electronic resources: MDPI, IEEE, Sciendo, Scopus and Science Direct. These sources were chosen due to their leading role in technological knowledge and the availability of numerous studies.

The study covered the entire territory of Ukraine, as well as individual enterprises that are the largest polluters in the country in the period from 2010 to 2023. For a more detailed analysis, statistical information was obtained from administrative data of the Ministry of Environmental Protection and Natural Resources of Ukraine and the State Statistics Service of Ukraine. Data based on the results of state statistical observations for 2010–2023 are given without taking into account the temporarily occupied territories of the Autonomous Republic of Crimea and the city of Sevastopol, as well as for 2014–2023 without taking into account part of the temporarily occupied territories in Donetsk and Luhansk regions. Information for 2022-2023 also does not include temporarily occupied territories captured by russia. (State Statistics Service of Ukraine).

The methodological basis of this study is the concept of a closed-loop green economy and the circular economy's role in ensuring the state's sustainable development. This concept considers socio-economic development as a process of social changes occurring within the limits determined by the ability of ecosystems to restore, absorb pollution and support the vital activity of current and future generations. The concept is formulated using the dominant point of view in the European Union, according to which the circular economy covers the entire life cycle of a product and is aimed at preserving its value for as long as possible. This is achieved by using multiple resources and materials in the production cycle and minimizing waste. Among the main advantages of the circular economy are innovative production processes, resource-saving, prevention of inefficient waste management, creation of new business opportunities and environmental friendliness. The study used analysis, synthesis, generalization, analogy and comparison methods. To investigate the statistical relationship between Ukraine's gross domestic product (GDP) and total air emissions over the period 2010–2023, a correlation analysis was employed. Specifically, the Pearson correlation coefficient was calculated to assess the strength and direction of the linear association between these two variables.

4.RESULTS

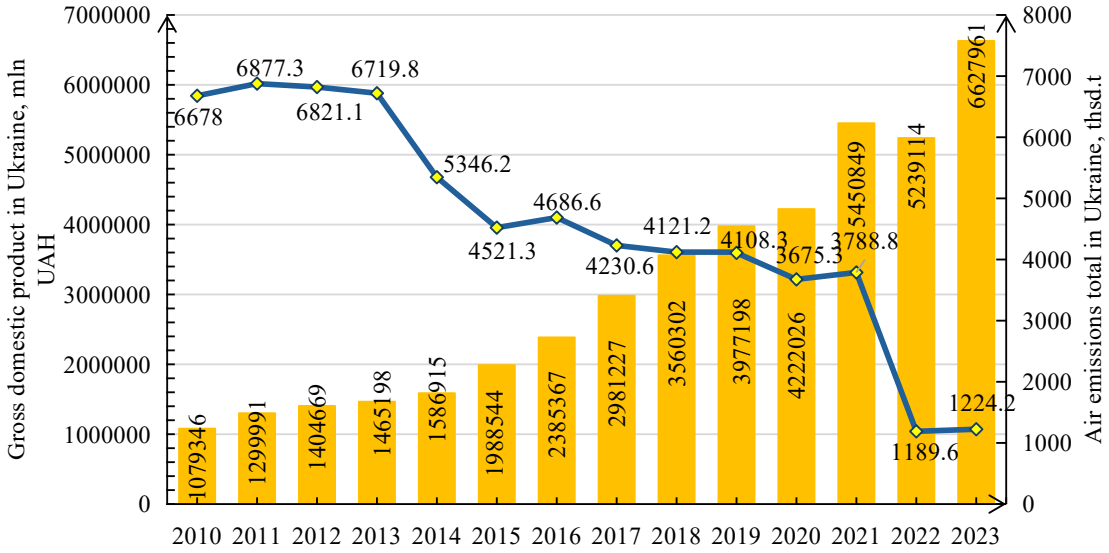
4.1. STATISTICAL STUDY OF THE IMPLEMENTATION OF THE CIRCULAR ECONOMY AS AN INNOVATIVE MECHANISM FOR PROTECTING ATMOSPHERIC AIR AND COMBATING CLIMATE CHANGE IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT OF UKRAINE

As a result of the full-scale war and terrorist actions of the Russian troops, Ukraine has experienced a significant burden on the environment and economy. Implementing the principles of the circular economy will contribute to creating conditions for the sustainable development of the regions of Ukraine and strengthening their socio-economic security.

GDP remains an important indicator in studies of the principles of implementing the circular economy (Kobylynska et al., 2023). To assess the effectiveness of the circular economy, we will compare GDP with other indicators, such as greenhouse gas emissions, the level of waste generation, etc.

Studies of the relationship between gross domestic product (GDP) and air emissions showed that from 2010 to 2023, air emissions total decreased by almost 5.5 times, from 6,678 thousand tons to 1,224 thousand tons (Fig. 1) (State Statistics Service of Ukraine).

Figure 1. Comparison of gross domestic product and air emissions total in Ukraine, 2010-2023, mln UAH / thsd.t



Source: developed by the author based on the data of the State Statistics Service of Ukraine

The most significant reduction in air emissions was observed after 2014, which is associated with the beginning of the war in Donbas and the decline of industry. In 2022–2023, a sharp drop in pollutant emissions is observed due to a full-scale war, the shutdown of enterprises and the relocation of production.

Analyzing the top 10 enterprises – the most significant air pollutants, it is worth noting that this anti-rating differs significantly in the period before and during the war (Table 1).

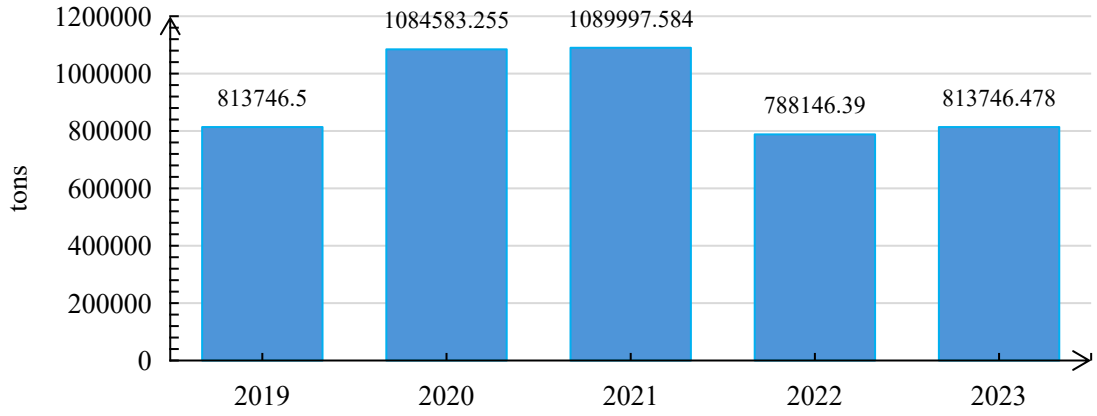
Table 1. Top 10 largest air pollutant enterprises in Ukraine in 2019-2023

rank	2023		2022		2021		2020		2019	
	enterprise	tons	enterprise	tons	enterprise	tons	enterprise	tons	enterprise	tons
1	DTEK Westenergy JSC	198859,7	DTEK Westenergy JSC	209678,4	PJSC Ilyich Iron And Steel Works Of Mariupol	258689,8	PJSC Ilyich Iron And Steel Works Of Mariupol	254099,1	PJSC Ilyich Iron And Steel Works Of Mariupol	247322,1
2	DTEK Pavlohradcoal PRJSC	134849,2	DTEK Pavlohradcoal PRJSC	117543,1	PJSC ArcelorMittal Kryvyi Rih. Metallurgical production prom №2	145796,4	PJSC ArcelorMittal Kryvyi Rih. Metallurgical production prom №2	139344,2	SS Burshtynska Thermal Power Plant. DTEK Westenergy JSC	169887,9
3	PJSC CG Pokrovs'ke	76139,3	PJSC CG Pokrovs'ke	100377,0	SS Burshtynska Thermal Power Plant. DTEK Westenergy JSC	145630,3	DTEK Kurahivs'ka TPP LLC	113336,2	PJSC ArcelorMittal Kryvyi Rih. Metallurgical production prom №2	150899,6
4	PJSC Kamet-Steel	75658,0	DTEK Skhidenerho TPP LLC	76220,8	DTEK Kurahivs'ka TPP LLC	109315,4	SS Burshtynska Thermal Power Plant. DTEK Westenergy JSC	109990,4	DTEK Kurahivs'ka TPP LLC	131391,8
5	DTEK Dniproenergy JSC	70154,6	PJSC Kamet-Steel	67997,2	PJSC CG Pokrovs'ke	96512,9	PJSC Dneprovsky Iron & Steel Integrated Works	91608,5	SS Zaporizhzhia thermal power station. DTEK Dniproenergy JSC	98650,9
6	PJSC ArcelorMittal Kryvyi Rih	63552,1	DTEK Dniproenergy JSC	56468,7	SS Zaporizhzhia thermal power station. DTEK Dniproenergy JSC	76472,4	SS Zaporizhzhia thermal power station. DTEK Dniproenergy JSC	86277,0	PJSC Azovstal Iron And Steel Works	81404,8
7	PJSC Centrenergo	60463,0	PJSC ArcelorMittal Kryvyi Rih	55634,8	PJSC Azovstal Iron And Steel Works	74058,1	PJSC Azovstal Iron And Steel Works	84323,5	PJSC Dneprovsky Iron & Steel Integrated Works	78090,5
8	DTEK Kurahivs'ka TPP LLC	59278,8	PJSC Centrenergo	41315,8	Vuhlehirska power station PJSC Centrenergo	70528,6	PJSC CG Pokrovs'ke	74983,8	Vuhlehirska power station PJSC Centrenergo	77590,2
9	PJSC Zaporizhstal	45803,0	PJSC Zaporizhstal	35856,4	PJSC ArcelorMittal Kryvyi Rih. Metallurgical Prod.	58319,7	Vuhlehirska power station PJSC Centrenergo	67289,5	PJSC ArcelorMittal Kryvyi Rih. Metallurgical Production	73375,1
10	PJSC Cherkasky Chemical Fiber	28988,8	SE L'vivvughiliya	27054,3	Ladyzhynska thermal power station DTEK Westenergy JSC	54674,1	PJSC ArcelorMittal Kryvyi Rih. Metallurgical Production	63331,1	Ladyzhynska thermal power station DTEK Westenergy JSC	70844,3

Source: developed by the author based on the data of the State Statistics Service of Ukraine

Unfortunately, the most significant number of enterprises among Ukraine's top 10 largest air polluters in 2019-2021 left it not because of the implementation of circular economy practices but because they were entirely or partially destroyed due to a full-scale war. However, if we examine the total emissions of the 10 largest air polluters in Ukraine in the period 2019-2023, not from the perspective of changing the rating of the enterprises themselves but from the perspective of the dynamics of their emissions (Fig. 2), it is worth noting in the context of the implementation of a circular economy, it is worth noting that the growth in emissions in 2020-2021 is a sign of a linear economy.

Figure 2. Emissions of the top 10 largest air polluters in Ukraine in 2019-2023, tons



Source: developed by the author based on the data of the State Statistics Service of Ukraine

The increase in emissions in these years indicates the predominance of the traditional, linear production model: "take → use → throw away". This is when insufficient attention was paid to resource efficiency, technological modernization, and the implementation of closed cycles, which are key aspects of the circular model.

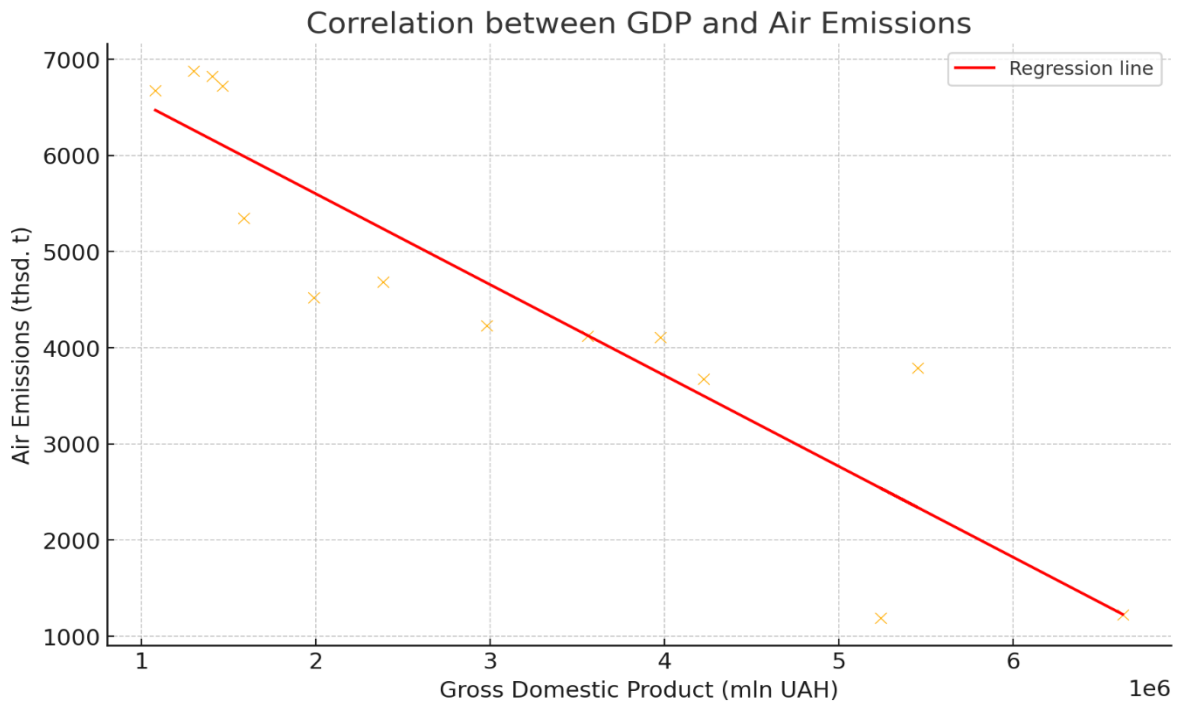
As noted earlier, the drop in emissions in 2022 was a forced consequence of the war, not the result of sustainable innovation or the transition to a circular economy. This is more of a forced "air cleaning" than the achievement of a decarbonization policy or a real transition to "green" production.

In 2023, a return to the level of 2019 is observed. Restoring indicators to pre-war levels is a crucial moment to launch circular approaches. This is a good time for the mass implementation of environmentally friendly technologies, expansion of renewable energy, and modernization of enterprises with an orientation towards reducing emissions and reusing resources.

As Figure 1 shows, GDP in Ukraine increased 6 times (nominally). This indicates a relative "decoupling" between economic growth and the level of air emissions. It is worth noting that the relative reduction in pollution against the background of GDP growth is a positive signal for sustainable development. The correlation analysis was conducted to examine the statistical relationship between Ukraine's gross domestic product (GDP) and total air emissions over the period 2010–2023 (Fig. 3). The Pearson correlation coefficient was calculated to quantify the strength and direction of the linear relationship between these two variables.

The analysis yielded a Pearson correlation coefficient of -0.91 with a p-value of 0.000005, indicating a strong and statistically significant negative correlation. This suggests that, as GDP increased over time, the level of air emissions tended to decline. The negative sign reflects an inverse relationship, implying that economic growth in Ukraine has been accompanied by a notable reduction in atmospheric pollutants.

Figure 3. Correlation between GDP and Air Emissions



Source: developed by the author based on the data of the State Statistics Service of Ukraine

This finding indicative of multiple structural changes within the economy, including improvements in energy efficiency, shifts toward less carbon-intensive sectors, technological modernization, or the impact of environmental regulations and policies aligned with EU standards. The observed decoupling between economic growth and environmental degradation is a key indicator of sustainable development and supports the hypothesis that economic progress in Ukraine does not increased environmental burdens. Such results underscore the importance of integrating environmental considerations into economic planning and reinforce the relevance of green growth strategies in post-industrial and post-crisis recovery contexts.

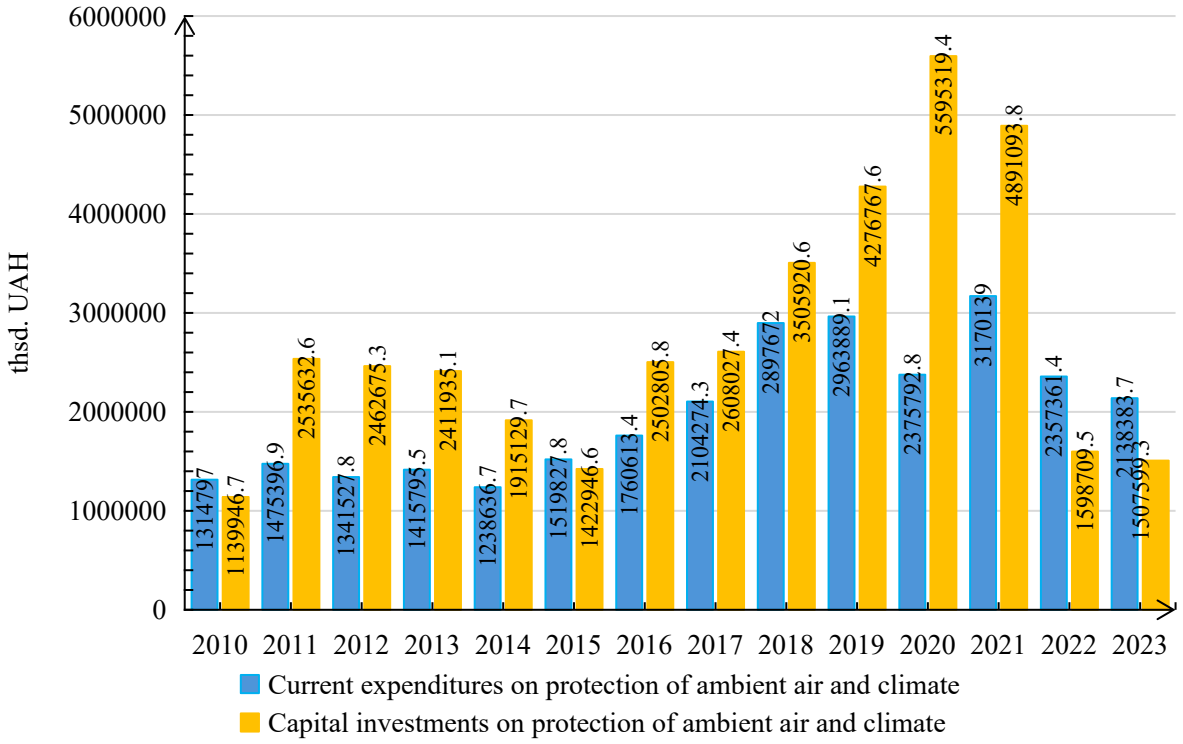
Important indicators of the effectiveness of environmental protection policy are current expenditures and capital investments on protection of ambient air and climate change problems (Fig. 4) (State Statistics Service of Ukraine).

Thus, current expenditures on air protection and climate change issues in Ukraine had a general upward trend from 2010 (1.3 billion UAH) to a peak in 2021 (3.17 billion UAH). After 2021, a decline began: 2.35 billion in 2022 and 2.13 billion in 2023. A significant increase in this indicator occurred in 2016–2021. Capital investments in air protection and climate change issues in Ukraine, which in 2010 amounted to 1.14 billion UAH, showed significant growth in 2011, amounting to 2.5 billion UAH (more than 2 times). The peak of capital investments in air protection and climate change issues is reached in 2020 — 5.6 billion UAH, after which a sharp drop is observed: 1.6 billion in 2022 and 1.5 billion in 2023 (State Statistics Service of Ukraine).

It is worth noting that in 2020, despite the COVID-19 pandemic, capital investments were the highest. This may result from the implementation of previously planned projects or international support. 2022–2023 is an anti-crisis period when environmental investments are significantly reduced.

Capital investments lay the foundation for circular transformation. Current costs support this transformation, ensuring its sustainability. The synchronous growth of these costs from 2015 to 2021 indicates an active environmental policy and the desire for circularity. This is logical – large eco-projects require: capital investments in infrastructure (purification systems, filters), ongoing costs for maintenance, modernization and monitoring.

Figure 4. Current expenditures and capital investments on protection of ambient air and climate change problems in Ukraine in 2010–2023, thousand UAH



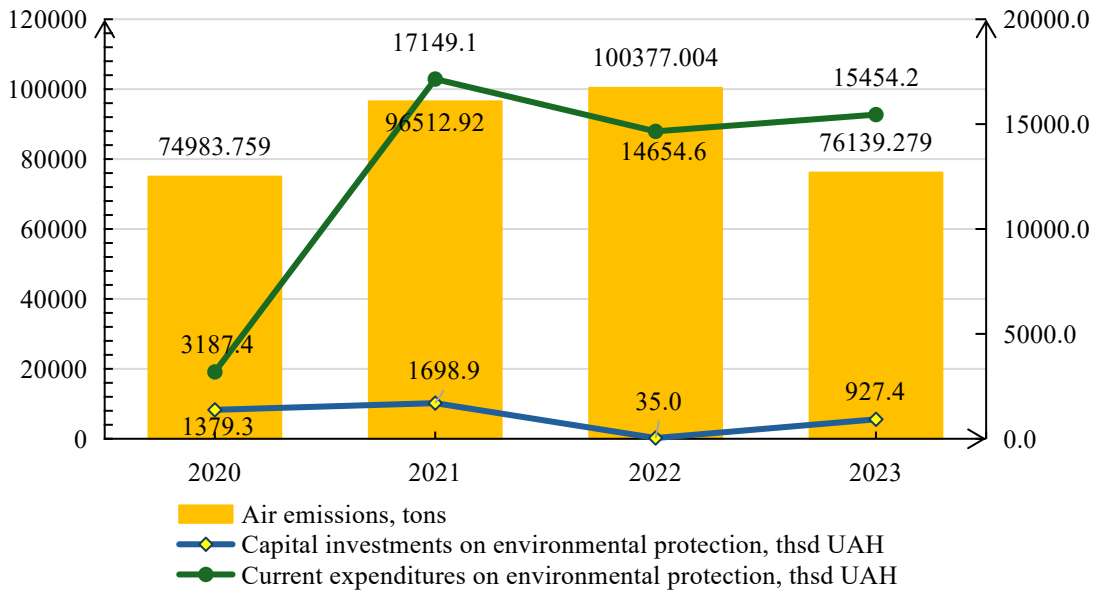
Source: developed by the author based on the data of the State Statistics Service of Ukraine

As for capital investments in atmospheric air protection and the problem of climate change as a driver of circularity, their peak in 2018–2021 (3.5–5.6 billion UAH) is justified by the launch of innovative solutions (replacement of equipment with low-carbon ones), the introduction of cyclical processes, such as heat recovery, reuse of CO_2 emissions. These infrastructural changes lay the foundation for long-term "green" practices. A sharp drop after 2021 indicates the risk of stopping or regressing circular processes. This is due to the war, the prioritization of security and defence spending, and the general economic downturn (State Statistics Service of Ukraine).

To study the Comparison between the volume of emissions of particulate pollutants into the air and the volume of capital investments and current environmental protection costs in the context of a circular economy at the micro level, PJSC CG Pokrovs'ke was selected, which for the last 4 years has been among the top 10 largest air polluters in Ukraine (Table 1, Fig 5).

Emissions of particulate pollutants into the air at PJSC CG Pokrovs'ke increased from 2020 to 2022 (+34%), and in 2023 fell almost to the level of 2020. Capital investments fell sharply in 2022 – only 35 thousand UAH, but partially recovered in 2023. Current expenses increased sharply in 2021 (by 5+ times) and have been maintained at a high level. The enterprise actively fought emissions in 2021, investing in the current system support. 2022 became the most critical year: no investments, but current expenses were still maintained. In 2023, there is a restoration of the course towards environmental efficiency. The enterprise may have a high potential for circularity if it maintains the investment level and continues reducing emissions.

Figure 5. Relationship between the volume of emissions of particulate pollutants into the air and the volume of capital investments and current environmental protection costs of PJSC CG Pokrovs'ke in 2019-2023



Source: developed by the author based on the data of the State Statistics Service of Ukraine

Therefore, both at the macro and micro levels, to restore the course towards circular economy, it is necessary to stabilize the situation, obtain external support and integrate the green economy into the recovery plan of Ukraine. In modern economic conditions, the management of Ukrainian enterprises often faces numerous problems related to the effective allocation of resources, raw materials and materials. This is necessary to ensure positive performance indicator dynamics and reduce harmful environmental emissions. The low level of competitiveness of the Ukrainian industry today is due to the lack of innovative technologies and insufficient material, technical and resource support. Additional difficulties arise due to the latest challenges of the world system, such as the transformation of the resource-based model of development, globalization, the fourth industrial revolution and, in recent years, war.

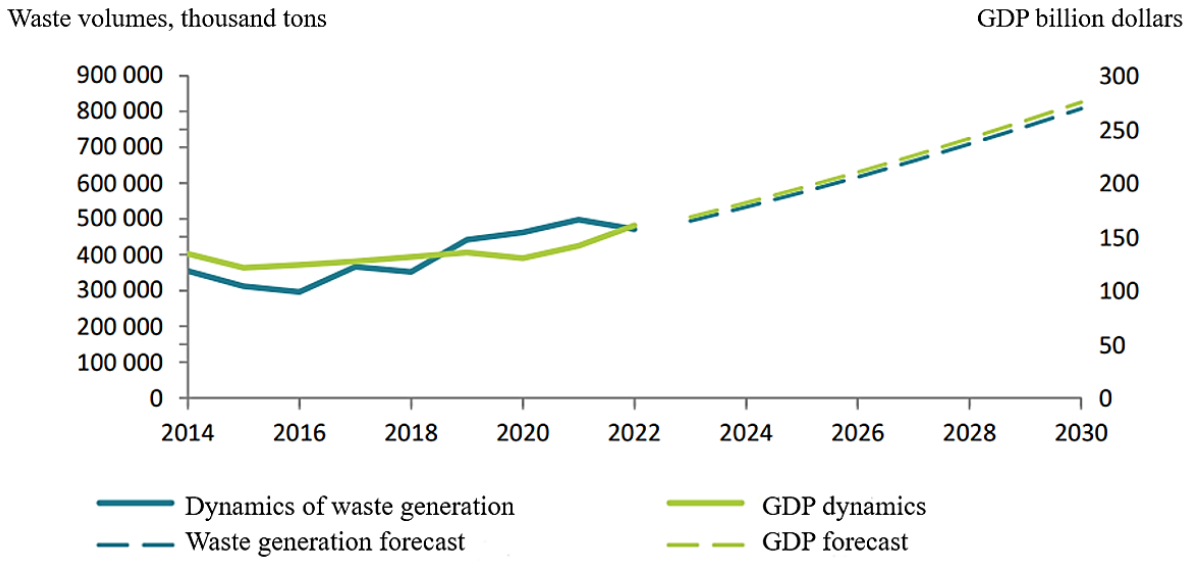
4.2. STATISTICAL STUDY OF THE IMPLEMENTATION OF THE CIRCULAR ECONOMY AS AN INNOVATIVE TOOL FOR COMBATING CLIMATE CHANGE THROUGH EFFECTIVE WASTE MANAGEMENT IN THE CONTEXT OF SUSTAINABLE DEVELOPMENT OF UKRAINE

For Ukraine, the transition to a closed-loop economy is significant and relevant since, before the war, the annual volume of household waste was about 11 million tons. According to the State Statistics Service, over 25 billion tons of waste have been accumulated in Ukraine, of which more than 4 billion tons are toxic, and 23 thousand tons are prohibited and unsuitable for use with pesticides and toxic chemicals. As a rule, Waste disposal in Ukraine includes incineration and removal to specially designated places and facilities. The circular economy can become an effective tool for solving the problem of excessive accumulation of waste that arose both before the war and during hostilities.

High level of waste generation (11.1 tons per person per year) is twice as high as that of EU countries, which is 4.8 tons. Low recycling and recovery rates have resulted in significant amounts of waste accumulating in Ukraine yearly. Under the Association Agreement between Ukraine and the EU, Ukraine has committed to align its national legislation with EU legislation on environmental protection, waste management, climate change, ozone layer protection, industrial pollution and air quality. Ukraine has adopted a waste reduction plan by 2030.

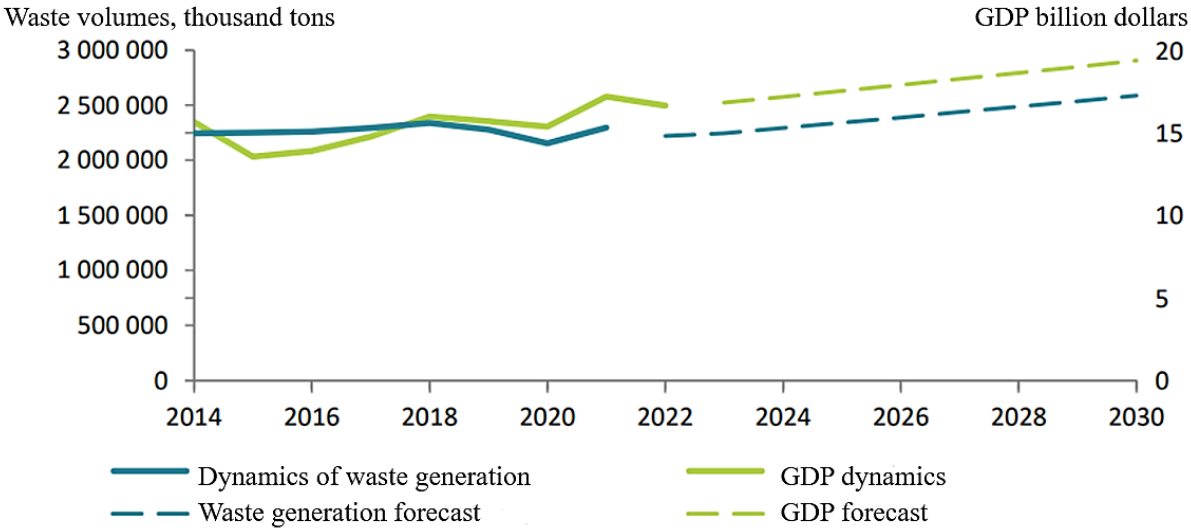
In the structure of household waste management in the EU in 2021, 49.6% of waste was sent for recycling. Compared to Ukraine, where only up to 8% of household waste was recycled, this indicates a gap in waste treatment methods. Stable GDP growth leads to increased production and, accordingly, an increase in waste. The task of the circular economy is to bridge the gap between economic growth and increased waste generation (Fig. 6-7) (Circular economy strategy - Green Mind, 2024).

Figure 6. Relationship between waste generation and GDP growth in Ukraine, thousand tons / billion dollars



Source: Circular economy strategy - Green Mind, 2024.

Figure 7. Relationship between waste generation and GDP growth in EU countries, thousand tons / billion dollars



Source: Circular economy strategy - Green Mind, 2024.

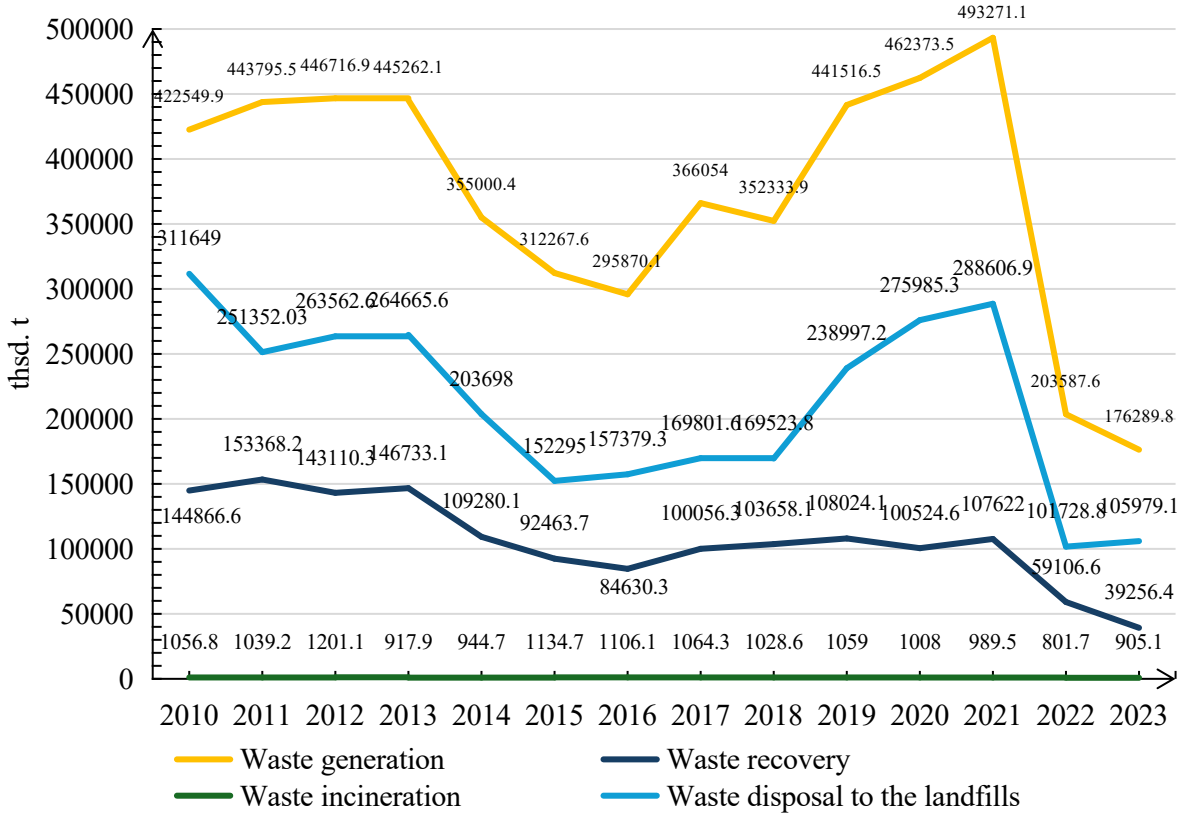
Key problems with waste in the direction of resources for recovery:

1. Lack of waste accounting mechanisms, in particular: precise mechanisms for accounting for waste volumes and their structure have not been introduced; a system for informing about the volumes of waste processing in the extractive industry has not been introduced; a separate legal framework for managing waste in the extractive industry has not been established.
2. Lack of regulation of disposal: the problem of disposal of waste generated at specially designated sites has not been resolved; the problem of the lack of a sufficient number of disposal enterprises in Ukraine for the reuse of slags, production tailings, and wastewater has not been resolved.
3. The problem of waste transportation: much waste is located in the eastern part of Ukraine and has no possibility for transportation; the processing complex should be located in a transport hub where it will be easy to transport waste for further processing; alternatively, the creation of a joint processing complex requires cooperation between different manufacturers.

According to official data from the State Statistics Service of Ukraine, in recent years, the organization of economic activities of enterprises based on a closed-loop economy for waste of hazard classes I–III has achieved only minor successes. At the same time, waste of hazard classes I–IV, including that generated in households, makes up 4 to 7% of the total volume of landfills in Ukraine. Analyzing waste management indicators in the structure of their generation (hazard classes I–IV), without taking into account the total volume of accumulated waste in specially designated places (waste disposal sites), we can conclude that only a third of the total amount of waste generated is utilized, while more than half is thrown away in designated places.

The study shows that waste generation is decreasing in Ukraine from 422 million tons in 2010 to 176 million tons in 2023, i.e., this indicator has more than doubled. (Fig. 8)

Figure 8. Waste generation and treatment of the I-IV hazard classes in Ukraine, 2010-2023, thousand tons



Source: developed by the author based on the data of the State Statistics Service of Ukraine

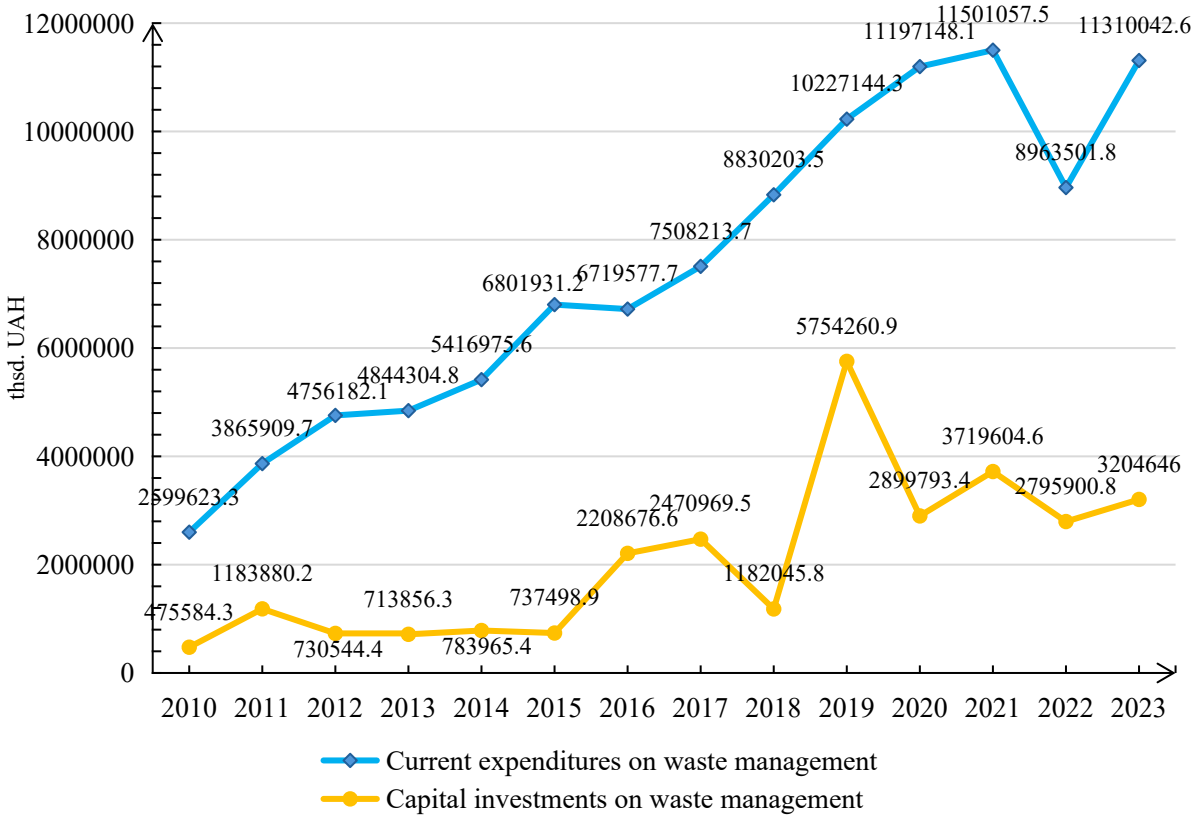
The sharp decrease in waste generation in 2022–2023 results from a full-scale war (less production, logistics, and construction). At the same time, waste recovery is also decreasing, from 144.9 million tons in 2010 to 39.3 million tons in 2023. Despite the drop in the total volume, the share of recovered waste is insignificant (~22% in 2023). The volumes of incinerated waste are consistently meagre – within 800–1100 thousand tons per year. This is less than 1% of the total volume, i.e., it can be said confidently that incineration as a disposal method is practically not used. The primary method of waste management in Ukraine today is landfilling. Constantly, over 50% of waste goes to landfills. In 2023, over 60% of the waste will be disposed of by landfilling, which indicates a low level of circularity.

Thus, the problems of applying the circular economy as an innovative development model in combating climate change and sustainable development are our country's high dependence on landfills, insufficient recovery and reuse of waste, and low level of thermal treatment (energy waste is not used). At the same time, all this opens up great potential for developing sorting, recycling, and composting infrastructure and reducing the volume of waste generated through the design of easily repaired/recycled products.

However, one of the main barriers to the innovative development of Ukrainian enterprises is the lack of state financial support for scientific and research institutions and a sufficiently strong base of institutions that control the rational use of innovative capital of enterprises.

Important indicators of the effectiveness of waste management policy are current expenses and capital investments in waste management (Fig. 9)

Figure 9. Current expenses and capital investments on waste management in Ukraine in 2010–2023, thousand UAH



Source: developed by the author based on the data of the State Statistics Service of Ukraine

Figure 9 shows a vast gap between current expenditure and capital investment in waste management. According to various estimates, the average capital investment required to develop a circular economy was approximately 3% of GDP per year, while in Ukraine, this figure is significantly less than 1% (European Investment Bank).

A large amount of waste from the destruction of facilities causes damage to the country's territory, pollutes water, soil, and air, and produces greenhouse gas emissions, leading to climate change (Kolesnichenko, O. 2023). According to the calculations of the Ministry of Environmental Protection and Natural Resources of Ukraine, the amount of damage caused to the country's environment was approximately 2 trillion UAH.

As a result of the war in Ukraine, about 11-12 million tons of destruction waste were generated (excluding destroyed equipment). The Government has approved the Procedure for Handling Waste Generated in Connection with Damage (Destruction) of Buildings and Structures as a Result of Hostilities (Resolution No. 1073 of the Cabinet of Ministers of Ukraine dated September 27, 2022). Communities are taking out destroyed waste and putting it in temporary storage sites.

According to local government bodies, as of the beginning of 2024, about 600 thousand tons of destruction waste have accumulated in temporary storage sites and landfills in the territory controlled by Ukraine.

According to the World Bank's Third Rapid Damage and Needs Assessment (RDNA), the total cost of processing demolition waste will be almost $11 billion (RDNA3, December 2023), ~$5 billion

(RDNA2, January 2023), and $3.1 billion (RDNA1, August 2022). Thus, in one and a half years (August 2022 - December 2023), the total cost of waste processing has increased more than threefold.

The key problems of demolition waste management in Ukraine are:

1. Lack of targets: no targets have been set for preparing waste for reuse, recycling, other material recovery, including backfilling; the procedure for their implementation has been approved.
2. Lack of incentives: no practice of selective demolition of buildings and incentives for reuse and recycling of construction and demolition waste has been implemented; low tax on waste disposal, no ban on placing construction waste in landfills; no taxes on primary resources and materials to encourage the use of secondary ones.
3. Low level of regulation: no defined ownership of construction waste (building owner, dismantling contractor, sorting or recycling operator); no pre-demolition audits required; no requirement to develop a waste management plan for dismantling works.
4. Lack of infrastructure: infrastructure for preparation for reuse and recycling of waste is not developed; market for building materials from secondary raw materials is not developed.

Having analyzed pollution indicators and the results of implementing a circular-oriented economic model, it can be stated that the pollution and waste volumes are quite significant. Accordingly, introducing the main mechanisms of a circular-oriented model at the national level is necessary for further economic development.

All this emphasizes the need to implement a new alternative resource and waste management model to balance economic interests, the ecological system and the rational use of nature.

Ukraine is beginning to actively apply modern innovations to increase its productivity and reduce the negative impact on the environment. Some sectors of the economy and enterprises have been implementing the principles of the circular economy in their activities long before the progressiveness, environmental friendliness, economic feasibility, and relevance of this concept were recognized. Given the current circumstances, increasing efforts and drawing attention to these innovative enterprises are important to implement the circular economy principles.

An important component is the need to organize production so that the waste of one becomes a resource for another, minimizing the need for raw materials.

Researching the circular economy model and directions for improving waste management in Ukraine is one of the directions that can solve the problems of secondary use and recycling of waste, and the gradual transition to a circular production model.

In addition, studies show that thoughtful green spending can counteract the environmental crises caused by climate change and pollution while providing social benefits. Green innovation's primary focus is minimizing the negative impact of production and consumption activities on the environment.

This can be achieved through the use of renewable energy sources. In addition, reusing and recycling materials and product elements reduces the need for additional resources and production processes. Implementing the circular economy model also saves material resources due to a longer product life cycle. Thus, fewer additional resources will be required to ensure the national economy.

The implementation of circular economy methods in Ukraine is accompanied by several features and obstacles that complicate the transition to a renewable type of production. One of the main reasons is the opacity of the secondary raw materials market, where more than 50% of the volumes are in the shadows. In addition, the market for recycling and waste-free technologies, particularly innovative ones, is at the initial stage of development. Another negative factor is the lack of tariffs for recycling secondary resources. There are 6.5 thousand authorized landfills in Ukraine, of which 25% do not meet environmental standards, and 35 thousand natural landfills.

For the effective development of the circular economy, it is necessary to adopt relevant regulatory legal acts at the state's top leadership level. The beginning has already been made - the Cabinet of Ministers of Ukraine adopted the Resolution of 25.04.2018 No. 313 "On the establishment of the Co-

ordination Council on the implementation of the National Waste Management Strategy in Ukraine until 2030" and approved the National Waste Management Strategy in Ukraine until 2030.

The insufficient development of the circular economy in Ukraine is due to the ongoing unprovoked and unjustified aggressive war of Russia against Ukraine, the imperfection of the institutional environment, and insufficient business motivation. The implementation of the principles of the circular economy in Ukraine requires a systemic and comprehensive restructuring based on the legislative framework, the introduction of innovative technologies, the digitalization of production and trade processes, the financing of environmental initiatives, the stimulation of innovative eco-friendly business models, the formation of environmental awareness in society and the formation of the habit of broader use of sustainable products and the creation of new ways of interaction between producers and consumers, the stimulation of the emergence and development of innovative professions. Ukraine's faster adaptation to the requirements of the CEAP can be realized by joining the Global Alliance for the Circular Economy (GAERCE) in matters of bringing the functioning of the national economy closer to the principles of circularity; supporting the transition of businesses to circular models of work, through cooperation and interaction with international initiatives similar to SWITCH to Green; closer cooperation with the EU on circular economy issues; harmonization of several directives and strategies and waste reduction.

4.3. SWOT ANALYSIS OF THE IMPLEMENTATION OF CIRCULARIZATION OF PRODUCTION PROCESSES IN UKRAINE

With systematic state measures for deregulation, stimulation of eco-innovation and harmonization of domestic legislation with European standards, implementing the circular economy principles can significantly optimize resource flows, minimize the negative impact on the environment and strengthen the competitiveness of Ukrainian industry.

The SWOT analysis shows that despite several problems and threats, Ukraine has a relatively favourable basis for developing and gradually implementing the circular economy model, provided that the existing strengths and opportunities are carefully considered (Fig. 10).

Analysis of potential benefits from Ukraine's transition to a circular production model in different time horizons allows us to identify several important environmental and economic effects:

- saving money on waste disposal by involving it in production cycles as secondary raw materials;
- creating new jobs in the recycling, repair, and remanufacturing sectors;
- reducing greenhouse gas emissions from waste processing compared to landfilling;
- improving the environmental image of domestic companies in foreign markets;
- saving money on the import of primary raw materials due to the use of secondary resources, etc. (Hakhovych at all, 2020; Hurochkina & Budzynska, 2020).

In addition to direct economic benefits, the transition to circular production models will have important positive externalities for the environment and society. This includes protecting and restoring ecosystems, preserving biodiversity, minimizing pollution, and improving the population's quality of life.

Realizing the circular economy potential will allow Ukraine to make significant progress towards sustainable development, strengthen economic and resource security, gain competitive advantages in external markets, and ensure the harmonious coexistence of society and nature.

The importance of circular economy principles for achieving sustainable development goals cannot be overstated. As Ukraine seeks to rebuild and develop its economy in the post-war period, implementing a circular economy can be important in promoting sustainability, resource efficiency, and environmental protection. By adhering to the principles and goals of a circular economy, Ukraine can adapt its economic strategies to promote long-term sustainability and address pressing issues such as waste management and resource scarcity. This transition to a circular economy can lay the foundation for Ukraine's more resilient, resource-efficient, and sustainable economic future.

Addressing resource scarcity is critical to economic development, especially in the post-war period when recovery efforts require effective resource management. The circular economy represents a strategic approach to mitigating resource scarcity by promoting reuse, recycling, and repurposing of materials. In Ukraine, implementing circular economy principles can help mitigate resource constraints by maximizing the value derived from existing resources and reducing waste generation. By adopting a circular economy system, Ukraine can increase resource efficiency, minimize dependence on external resources, and build a more resilient economy capable of sustainable growth.

Figer 10. SWOT analysis of the implementation of circularization of production processes in Ukraine

SWOT analysis of the implementation of circularization of production processes in Ukraine

Strengths

- High potential for resource conservation and circular business models in resource-intensive industries (metallurgy, chemical industry, agro-industrial complex).
- Availability of significant volumes of industrial and agricultural waste that can be used as secondary raw materials.
- Possibility of attracting foreign investment and transfer of advanced circular technologies in the event of systemic reforms.
- Potential for developing the processing and recycling industry and creating new "green" jobs.
- Growing environmental awareness of society and interest in the principles of sustainable development.

Weaknesses

- Imperfect regulatory framework, lack of clear incentives for implementing circular practices.
- Lack of investment resources and state funding for "green" initiatives.
- Outdated waste management infrastructure, dominance of landfill.
- Low level of corporate social responsibility of business and "green" thinking.
- Lack of qualified personnel and educational programs on the circular economy.

Opportunities

- Harmonization of legislation with European standards and directives in the field of circular economy.
- Development of public-private partnerships for the implementation of circular projects.
- Using the opportunities of industrial and agrosymbiosis to create regional closed cycles.
- Export of circular products and services to Western markets in case of sufficient quality and competitiveness.
- International technical assistance, grants and soft loans for circular initiatives.
- Strengthening the country's energy and resource independence.

Threats

- Delays in waste management reform and lack of political will.
- Possible resistance from linear business models due to a lack of understanding of a circular approach's benefits.
- Lack of skilled labour and "brain drain" in case of insufficient support for circular initiatives.
- Economic and political instability, risk of devaluation of investments in circular projects.
- Unpreparedness of society for a radical change in consumption habits and worldview.
- Lobbying for the status quo by some industrial and financial players.

Source: developed by the author

One of the key benefits of implementing a circular economy model in post-war Ukraine is to stimulate innovation and entrepreneurship.

5. CONCLUSIONS

This study highlights the strategic relevance of transitioning to a circular economy (CE) in Ukraine as a key pathway toward sustainable development, climate resilience, and post-war recovery. The analysis reveals a statistically significant decoupling between GDP growth and air emissions over the period 2010–2023, indicating that economic advancement is not inherently linked to environmental degradation. However, the reduction in emissions during recent years was largely driven by wartime industrial decline rather than systemic implementation of circular practices.

The research further identifies critical weaknesses in Ukraine's waste management system, including overreliance on landfilling, low recycling rates, and insufficient capital investment in circular infrastructure. Case studies at both macro and micro levels demonstrate the potential for circular transformation but also expose gaps in policy, funding, regulation, and institutional capacity.

Despite the current challenges, Ukraine possesses notable sectoral potential - particularly in metallurgy, construction, chemical processing, and the agro-industrial complex - to adopt circular economy principles. Strengthening regulatory frameworks, scaling up innovation ecosystems, enhancing environmental governance, and fostering public-private partnerships will be essential to accelerate this transition.

The findings underscore the urgency of integrating circular economy models into Ukraine's national recovery strategy. Doing so will not only support environmental restoration and economic revitalization but also align Ukraine more closely with EU standards and global sustainability objectives. Continued research, policy reform, and coordinated stakeholder action are needed to unlock the full potential of circularity in shaping Ukraine's resilient, low-carbon, and resource-efficient future.

REFERENCES

Aceleanu, M.I., Serban, A.C., Suciu, M-C., Bitoiu, T.I. (2019) The management of municipal waste through circular economy in the context of smart cities development. *IEEE Access,* 7, 133602–133614. https://doi.org/10.1109/access.2019.2928999

Alhawari, O., Awan, U., Bhutta, M. K. S., & Ülkü, M. A. (2021). Insights from Circular Economy Literature: A Review of Extant Definitions and Unravelling Paths to Future Research. *Sustainability*, *13*(2), 859. https://doi.org/10.3390/su13020859

Almagtome, A.H., Al-Yasiri, A.J., Ali, R.S., Kadhim, H.L., Bekheet, H.N. (2020) Circular economy initiatives through energy accounting and sustainable energy performance under integrated reporting framework. *International Journal of Mathematical, Engineering and Management Sciences,* 5(6), 1032–1045. https://doi.org/10.33889/ijmems.2020.5.6.079

Atabaki, M.S., Mohammadi, M., Naderi, B. (2020) New robust optimization models for closed-loop supply chain of durable products: towards a circular economy. *Computers & Industrial Engineering*, 146, 106520. https://doi.org/10.1016/j.cie.2020.106520

Chioatto, E., Sospiro, P. (2023) Transition from waste management to circular economy: the European Union roadmap. *Environment, Development and Sustainability*, 25, 249-276 https://doi.org/10.1007/s10668-021-02050-3

Circular Economy. The World Economic Forum. https://www.weforum.org/stories/circular-economy/

Cucciniello, R., & Cespi, D. (2018). Recycling within the Chemical Industry: The Circular Economy Era. *Recycling*, 3(2), 22. https://doi.org/10.3390/recycling3020022

Dantas, T.E.T., de-Souza, E.D., Destro, I.R., Hammes, G., Rodriguez, C.M.T., Soares, S.R. (2021) How the combination of circular economy and industry 4.0 can contribute towards achieving the sustainable development goals. *Sustainable Production and Consumption*, 26, 213–227. https://doi.org/10.1016/j.spc.2020.10.005

Durán-Romero, G., López, A.M., Beliaeva, T., Ferasso, M., Garonne, C., Jones, P. (2020) Bridging the gap between circular economy and climate change mitigation policies through eco-innovations and Quintuple Helix Model. *Technological Forecasting and Social Change*, 160, 120646. https://doi.org/10.1016/j.techfore.2020.120246

Fawzy, S., Osman, A.I., Yang, H., Doran, J., Rooney, D.W. (2021) Industrial biochar systems for atmospheric carbon removal: a review. *Environmental Chemistry Letters*, 19, 3023–3055. https://doi.org/10.1007/s10311-021-01210-1

Filho, W. L., Frizzo, K., Eustachio, J. H. P. P., Tsani, S., Özuyar, P. G. (2024)Integrating climate change practices in a circular economy context—the perspective from chemical enterprises. *Sustainable Development*, 3(32), 2489-2505. https://doi.org/10.1002/sd.2796

Geissdoerfer, M., Savaget, P., Bocken, N.M.P., Hultink, E. J. (2017), The Circular Economy: a new sustainability paradigm. *Journal of Cleaner Production,* 10, 757–768. https://doi.org/10.1016/j.jclepro.2016.12.048

Gheewala, S.H. (2014). Material recycling in a circular economy - a systems view. *Wiley Interdisciplinary Reviews: Energy and Environment,* 13 (1). https://ideas.repec.org/a/bla/wireae/v13y2024i1ne503.html

Global Resources Outlook. (2019) Natural Resources For The Future We Want. United Nations Environment Programme. https://pure.iiasa.ac.at/id/eprint/15879/1/unep_252_global_resource_outlook_2019_web.pdf

Haas, W., Krausmann, F., Wiedenhofer, D., Heinz, M. (2015), How Circular is the Global Economy?: An Assessment of Material Flows, Waste Production, and Recycling in the European Union and the World in 2005. *Journal of Industrial Ecology*, 5(19), 765–777. https://doi.org/10.1111/jiec.12244

Hakhovych, N. H., Kushnirenko, O. M., Zarudna, O. S. (2020) Tsyrkuliarna ekonomika yak stratehichnyi priorytet rozvytku hlobalnykh lantsiuhiv dodanoi vartosti [Circular economy as a strategic priority for the development of global value chains]. *Economic Bulletin of Khmelnytsky University*, 46, 103-115. http://nbuv.gov.ua/UJRN/ecvu_2020_46_14

Hua, C., Chen, L., Liu, C., Yang, C. (2024). The effect of incentive policies on the diffusion of construction and demolition waste recycling: A government perspective. *Waste Management & Research*, 43(1), 50-61. https://doi.org/10.1177/0734242X241231400

Hurochkina, V. V., Budzynska, M. S. (2020) Tsyrkuliarna ekonomika: Ukrainski realii ta mozhlyvosti dlia promyslovykh pidpryiemstv [Circular economy: Ukrainian realities and opportunities for industrial enterprises]. *Ekonomichnyi visnyk. Seriia: finansy, oblik, opodatkuvannia*, 5, 52-56. https://core.ac.uk/download/pdf/328113907.pdf

Islam, K.M.N., Sarker, T., Taghizadeh-Hesary, F., Atri, A.C., Alam, M.S. (2021) Renewable energy generation from livestock waste for a sustainable circular economy in Bangladesh. *Renewable and Sustainable Energy Reviews*, 139, 110695. https://doi.org/10.1016/j.rser.2020.110695

Janik, A., Ryszko, A., & Szafraniec, M. (2020). Greenhouse Gases and Circular Economy Issues in Sustainability Reports from the Energy Sector in the European Union. *Energies*, 13(22), 5993. https://doi.org/10.3390/en13225993

Jose, R., Panigrahi, S.K., Patil, R.A., Fernando, Y., Ramakrishna, S. (2020) Artificial intelligence-driven circular economy as a key enabler for sustainable energy management. *Materials Circular Economy*, 2(8). https://doi.org/10.1007/s42824-020-00009-9

Kalebaila, N., Kapari, M., Nhamo, L., Mpandeli, S. (2024).The circular economy as a catalyst for environmental and human health. *Circular and Transformative Economy, s.l.* 139-158. https://www.taylorfrancis.com/chapters/oa-edit/10.1201/9781003327615-7/circular-economy-catalyst-environmental-human-health-nonhlanhla-kalebaila-mpho-kapari-luxon-nhamo-sylvester-mpandeli

Khan, S.A.R., Razzaq, A., Yu, Z., Miller, S. (2021) Industry 4.0 and circular economy practices: a new era business strategies for environmental sustainability. *Business Strategy and the Environment,* 32(7), 5119. https://doi.org/10.1002/bse.2853

Kirchherr, J., Reike, D., Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, 14, 221-232. https://doi.org/10.1016/j.resconrec.2017.09.005

Kobylynska, T., Hrynchak, N., Motuzka, O. (2024). The Impact Of The Circular Economy On Mitigating The Consequences Of Climate Change In The Regions Of Ukraine. *ECONOMICS - Innovative And Economics Research Journal*, 12(3), 115–131. https://doi.org/10.2478/eoik-2024-0037

Kolesnichenko, O. (2023). Problema na trylion. Shcho Ukraina robytyme iz sotniamy tysiach tonn smittia, stvorenoho rosiianamy [A trillion problem. What will Ukraine do with hundreds of thousands of tons of garbage created by the Russians]. Ekonomichna pravda. https://www.epravda.com.ua/publications/2023/06/19/701281/

Kurniawan, T. A., Liang, X., O'Callaghan, E., Goh, H., Othman, M. H. D., Avtar, R., & Kusworo, T. D. (2022). Transformation of Solid Waste Management in China: Moving towards Sustainability through Digitalization-Based Circular Economy. *Sustainability*, *14*(4), 2374. https://doi.org/10.3390/su14042374

Mahdhi, A., & Belgaroui, M. (2025). Environmental Efficiency Assessment of Tunisian Thermal Power Plants in the Presence of Technological Heterogeneity: Non-Parametric Meta-Frontier. *Economics - Innovative and economics research journal*, *13*(2), 415–438. https://doi.org/10.2478/eoik-2025-0047

Ministry of Environmental Protection and Natural Resources of Ukraine. https://mepr.gov.ua/en/

Moore, B., Verfuerth, C., Minas, A.M., Tipping, C., Mander, S., Lorenzoni, I., Hoolohan, C., Jordan, A.J., Whitmarsh, L. (2021) Transformations for climate change mitigation: a systematic review of terminology, concepts, and characteristics. *Wiley interdisciplinary reviews: Climate Change*, 12(5). https://doi.org/10.1002/wcc.738

Murray, A., Skene, K., Haynes, K. (2015). The Circular Economy: An Interdisciplinary Exploration of the Concept and Application in a Global Context. *Journal of Business Ethics*, 140, 369-280. https://link.springer.com/article/10.1007/s10551-015-2693-2

National Waste Management Strategy in Ukraine until 2030. https://zakon.rada.gov.ua/laws/show/820-2017-%D1%80#Text

Nelles, M., Grünes, J., Morscheck G. (2016). Waste Management in Germany – Development to a Sustainable Circular Economy? *Procedia Environmental Sciences*, 35, 6-14. https://doi.org/10.1016/j.proenv.2016.07.001

Nikolaou, I.E., Jones, N., Stefanakis, A. (2021) Circular economy and sustainability: the past, the present and the future directions. *Circular Economy and Sustainability*, 1,1–20. https://doi.org/10.1007/s43615-021-00030-3

Nurgaliuly, A., & Smagulova, S. (2025). Economic Assessment of Energy Security of the Regions of Kazakhstan. *Economics - Innovative and economics research journal*, 13(2), 223–243. https://doi.org/10.2478/eoik-2025-0038

Osman, A.I., Fawzy, S., Farghali, M., El-Azazy, M., Elgarahy, A.M., Fahim, R.A., Maksoud, M.I.A.A., Ajlan, A.A., Yousry, M., Saleem, Y., Rooney, D.W. (2022) Biochar for agronomy, animal farming, anaerobic digestion, composting, water treatment, soil remediation, construction, energy storage, and carbon sequestration: a review. *Environmental Chemistry Letters*, 20, 2385-2485. https://doi.org/10.1007/s10311-022-01424-x

Pascale, A.D., Arbolino, R., Szopik-Depczyńska, K., Limosani, M., & Ioppolo, G. (2020). A systematic review for measuring circular economy: The 61 indicators. *Journal of Cleaner Production*, 124942. https://link.springer.com/article/10.1007/s11356-022-18580-w

Peña, C., Civit, B., Gallego-Schmid, A., Druckman, A., Pires, A.C., Weidema, B., Mieras, E., Wang, F., Fava, J., Canals, L.M.I., Cordella, M., Arbuckle, P., Valdivia, S., Fallaha, S., Motta, W. (2021) Using life cycle assessment to achieve a circular economy. *The International Journal of Life Cycle Assessment*, 26, 215–220. https://doi.org/10.1007/s11367-020-01856-z

Podlevska, O., Podlevskyi, A. (2023). Development Of Circular Economy In Modern Conditions. *ECONOMICS - Innovative and economics research journal*, 11(2), 97–112. https://doi.org/10.2478/eoik-2023-0025

Pryblyzno 10–12 milioniv tonn smittia utvorylosia v Ukraini vnaslidok viiny – Mindovkillia [Approximately 10–12 million tons of garbage were created in Ukraine as a result of the war – Ministry of Environment]. *Radio Svoboda* 23.06.2023. https://www.radiosvoboda.org/a/news-ukraina-viyna-smittiadovkillia/32467305.html

Reike, D., Vermeulen, W.J.V., Witjes, S. (2018). The circular economy: New or Refurbished as CE 3.0? – Exploring Controversies in the Conceptualization 15 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

Resolution No. 1073 of the Cabinet of Ministers of Ukraine dated September 27, 2022. «Procedure for handling waste generated as a result of damage to (or destruction of) buildings and structures due to hostilities, terrorist acts, sabotage, or work to liquidate their consequences. https://zakon.rada.gov.ua/laws/show/1073-2022-%D0%BF?lang=en#Text

Resolution No. 313 of the Cabinet of Ministers of Ukraine of 25.04.2018. On the establishment of the Coordination Council on the implementation of the National Waste Management Strategy in Ukraine until 2030. https://zakon.rada.gov.ua/laws/show/313-2018-%D0%BF#Text

Rincón-Moreno, J., Ormazábal, M., Álvarez, M.J., Jaca, C. (2020). Advancing circular economy performance indicators and their application in Spanish companies. *Journal of Cleaner Production*, 279 (1), 123605. https://doi.org/10.1016/j.jclepro.2020.123605

Sadhukhan, J., Dugmore, T. I. J., Matharu, A., Martinez-Hernandez, E., Aburto, J., Rahman, P. K. S. M., & Lynch, J. (2020). Perspectives on "Game Changer" Global Challenges for Sustainable 21st Century: Plant-Based Diet, Unavoidable Food Waste Biorefining, and Circular Economy. *Sustainability*, *12*(5), 1976. https://doi.org/10.3390/su12051976

Serrano, T., Aparcana, S., Bakhtiari, F., Laurent, A. (2021) Contribution of circular economy strategies to climate change mitigation: generic assessment methodology with focus on developing countries. *Journal of Industrial Ecology*, 25, 1382–1397. https://doi.org/10.1111/jiec.13178

Shen, K.- wen, Li, L., & Wang, J.-Q. (2020). Circular economy model for recycling waste resources under government participation: a case study in industrial waste water circulation in China. *Technological and Economic Development of Economy*, *26*(1), 21-47. https://doi.org/10.3846/tede.2019.11249

Silpa, K., Siddarth, S., Sarur, Ch. (2021). More Growth, Less Garbage. Urban Development Series. © World Bank. http://hdl.handle.net/10986/35998 doi:10.1596/978-1-4648-1329-0

State Statistics Service of Ukraine. https://www.ukrstat.gov.ua/

The EIB in the circular economy. European Investment Bank. https://www.eib.org/en/about/initiatives/circular-economy/index.htm

United Nations Framework Convention on Climate Change (2021) Nationally determined contributions under the Paris Agreement. https://unfccc.int/sites/default/files/resource/cma2021_08r01_E.pdf.

Wang, N., Guo, Z., Meng, F., Wang, H., Yin, J., Liu, Y. (2019) The circular economy and carbon footprint: a systematic accounting for typical coal-fuelled power industrial parks. *Journal of Cleaner Production,* 229, 1262–1273. https://doi.org/10.1016/j.jclepro.2019.05.064

World Bank Group (2024). Updated Ukraine Recovery and Reconstruction Needs Assessment Released. https://www.worldbank.org/en/news/press-release/2024/02/15/updated-ukraine-recovery-and-reconstruction-needs-assessment-released

World Population Prospects — Population Division. United Nations Population Division. https://population.un.org/wpp/

Yang, M., Chen, L., Wang, J., Msigwa, G., Osman, A.I., Fawzy, S., Rooney, D. W., Yap, P.-S. (2023). Circular economy strategies for combating climate change and other environmental issues. *Environmental Chemistry Letters,* 21, 55–80. https://doi.org/10.1007/s10311-022-01499-6

Yatsenko, O., Shvydanenko, O., & Shvydanenko, H. (2022). Circular economy as the basis of ensuring sustainable development of the country in the context of European integration. *Economics and Region*, (4(87), 150–167. https://doi.org/10.26906/EiR.2022.4(87).2794

Zhang, A., Venkatesh, V.G., Liu, Y., Wan, M., Qu, T., Huisingh, D. (2019) Barriers to smart waste management for a circular economy in China. *Journal of Cleaner Production*, 240, 118198. https://doi.org/10.1016/j.jclepro.2019.118198

Circular economy strategy - Green Mind. (2024). https://greenmind.com.ua/images/2024/prezentaciya_v_bazhana_mrg_30_05_2024.pdf