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Circular economy development in the context of war: Global challenges

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Abstract: The problem of resource scarcity is one of the most pressing in the world, and therefore conserving them through the introduction of a circular economy is an important factor in human development. The full-scale war in Ukraine, which began in February 2022, has had a significant impact on Europe's energy balance, and the importance of implementing a circular economy has grown even more. The study aims to investigate the impact of the war on the implementation of resource efficiency programs in Ukraine and the European Union. The methods used in the research process include analysis, synthesis, and statistical research. In addition, the method of open-source intelligence and the method of remote online survey were used as part of the empirical research. As a result, the dynamics of harmful emissions into the atmosphere and water resources of Ukraine from 2015 to 2022 were determined, which revealed a pronounced downward trend. The actual production of clean energy, the dynamics of fossil fuel use and the amount of carbon emissions in the European Union were also analyzed, which showed positive development. In the process, data on relocated Ukrainian enterprises that were moved away from the combat line to safer regions was used. The survey received qualified responses from the heads of large Ukrainian industries on the current situation with the implementation of measures to introduce a circular economy, the dynamics of financing these processes in recent years, and the impact of digitalization of production processes on business efficiency during full-scale hostilities. The respondents' answers were mostly positive about the existing measures and prospects. The practical significance of the study is to highlight the priorities of Ukraine's post-war reconstruction in the context of the circular economy concept.

Keywords: Environmental pollution, Resource conservation, Full-scale invasion, Relocation of production, Digitalization.

Resumo*: O problema da escassez de recursos é um dos mais prementes no mundo, pelo que a sua conservação através da introdução de uma economia circular é um fator importante para o desenvolvimento humano. A guerra em grande escala na Ucrânia, que começou em fevereiro de 2022, teve um impacto significativo no balanço energético da Europa, e a importância da implementação de uma economia circular aumentou ainda mais. O estudo tem como objetivo investigar o impacto da guerra na implementação de programas de eficiência de recursos na Ucrânia e na União Europeia. Os métodos utilizados no processo de investigação incluem a análise, a síntese e a investigação estatística. Além disso, o método de inteligência de fonte aberta e o método de inquérito remoto em linha foram utilizados como parte da investigação empírica. Como resultado, foi determinada a dinâmica das emissões nocivas para a atmosfera e para os recursos hídricos da Ucrânia de 2015 a 2022, o que revelou uma tendência pronunciada para a diminuição. Foram também analisadas a produção efectiva de energia limpa, a dinâmica da utilização de combustíveis fósseis e a quantidade de emissões de carbono na União Europeia, que revelaram uma evolução positiva. No processo, foram utilizados dados sobre as empresas ucranianas deslocalizadas que se afastaram da linha de combate para regiões mais seguras. O inquérito recebeu respostas qualificadas dos chefes das grandes indústrias ucranianas sobre a situação atual da aplicação de medidas para introduzir uma economia circular, a dinâmica do financiamento destes processos nos últimos anos e o impacto da digitalização dos processos de produção na eficiência das empresas durante as hostilidades em grande escala. As respostas dos inquiridos foram, na sua maioria, positivas em relação às medidas existentes e às perspectivas. O significado prático do estudo consiste em destacar as prioridades da reconstrução pós-guerra da Ucrânia no contexto do conceito de economia circular.*

Palavras-chave:*Poluição ambiental, Conservação dos recursos, Invasão total, Realocação da produção, Digitalização.*

Introduction

The challenges Ukraine faces in implementing circular economy principles in wartime are extremely complex and have different aspects. In particular, the conflict has affected infrastructure, production, logistics and other relevant areas in the following ways.Military conflict can lead to the destruction or damage of infrastructure, such as roads, bridges, railways, airports, and energy facilities. This impedes the movement of goods and resources, as well as the proper functioning of industrial enterprises and other sectors of the economy.An armed conflict may result in the cessation or significant reduction of production in certain sectors of the economy, in particular in heavy industry, agriculture and other industries that require significant resources and investment [1, 2].

The war may disrupt logistics processes, including the supply of raw materials and finished goods. This may lead to delays in the production and supply of goods, as well as to an increase in the cost of logistics services.The military conflict may lead to a decrease in the availability of financial resources and investments, which may complicate the implementation of the circular economy and other sustainable development strategies [3]. In these circumstances, it is important for Ukrainian scientists and experts to develop and implement adaptive strategies that

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take into account all aspects of the conflict and contribute to the stabilization of the economic situation in the country.

Zelinska et al. [1] studied the competitiveness of human resources at Ukrainian enterprises. With increasing competition in the global economy requiring companies to find the best ways to secure their market, highly educated and trained staff can be a strong advantage for Ukrainian business entities. In particular, the authors used economic and mathematical analysis to deeply investigate the concept of enterprise competitiveness and calculate the forecast values of the level of migration attractiveness of Ukraine. As a result of the study, it was proved that the solution to the problem of migration of highly qualified workers can be the formation of a separate personnel policy aimed at meeting the personal needs of employees, developing their creative abilities and training throughout their careers. However, the study did not examine migration processes in the context of forced internal displacement of workers in wartime. The problem of innovation in agriculture in the context of military invasion was studied by Berxolli et al. [2]. The authors pointed out that the country's agro-industrial complex (AIC), as the basis of economic development, has suffered perhaps the greatest losses since February 2022 – a large amount of arable land has either become inaccessible because of the occupation or is completely mined and contaminated. The solution is proposed in terms of innovation, agricultural intensification, and land conservation. Thus, temporary losses in the quantity of arable land should be compensated by quality, restoration technologies and resource conservation.

Potryvaieva and Palieiev [3], in turn, studied the experience of accounting outsourcing in the context of modern Ukrainian realities in the agro-industrial complex. Based on the similar experience of Western countries, the authors identified the following conditions for delegating accounting powers: legislative consolidation of the procedure for providing services, transparency towards clients, and preliminary determination of the amount of financial costs for the project. However, the authors did not pay sufficient attention to the aspects of the circular economy. The circular economy as an integral part of Ukraine's sustainable development was also studied by Dovgal et al. [4] who concluded that the circular economy is not just about recycling, but circular processes should be included long before the end of the product's life cycle. The concept of a circular economy involves participation in all stages of production of goods and preliminary planning of life cycle extension, increasing the potential for further reuse. The authors emphasise that this approach should ensure maximum efficiency and help Ukraine gain significant benefits, starting from the stage of determining the cost of raw materials to cheaper packaging technologies, but do not propose specific mechanisms for such changes.

Dovgal [5] focuses more on the organisational and economic principles of creating and implementing a circular business model and proposes stages of its implementation in practice. Analysing the current practice of successful implementation of such models and exploring different types of closed-loop business organisations, the author presents structural diagrams of various examples of closed-loop economies, considering the specifics of value added. The innovative approach underlying the paradigm of the resource-saving economy is impossible without the digitalisation of accounting and management automation. Ukraine, as a leading agrarian country, has been particularly motivated over the past year and a half to implement such principles in its agriculture. Potryvaieva et al. [6] found that the introduction of management automation in agriculture is a rather lengthy process, since, in addition to significant investments in equipment, such projects will also require staff training. The authors formulated principles for the development of an up-to-date information space that can be used in the business environment of the agricultural sector but did not pay sufficient attention to the impact of a full-scale war on the transformation of this environment.

Thus, as confirmed by numerous colleagues, Ukraine's potential for developing a circular economy is extremely high, but so far insufficient attention has been paid to the impact of the war on such processes. Since access to some information is restricted for security reasons under martial law, the study aims to find the necessary data in the public domain and conduct a survey of direct market participants. The objective of the study is to examine how the implementation of resource efficiency programs in Ukraine and the European Union has been affected by the war.

The objectives of the study were as follows:

1. To study the impact of the war on the reorganization of energy security programs and the development of the circular economy in the European Union.

2. To analyse Ukraine's strategies to restore the development of the circular economy after the war and their impact on environmental recovery and energy efficiency.

3. To explore the benefits and opportunities for the transition to a circular economy in the context of post-war recovery, in particular in certain regions, including Crimea.

1. Materials and Methods

An analysis of the available indicators of the circular economy, such as air pollution from carbon emissions and surface water pollution in the Azov and Black Seas, was used in the study. Given the relatively short period under study – one and a half years – there is no extensive statistical data on the impact of full-scale military operations on the environment that could be analysed in dynamics, but the synthesis method was used to formulate logical constructions for further development of the situation. In addition, using the method of statistical tests, the article examines the indicators of the circular economy development of the European Union (EU) countries and calculates

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the dependence of the existing changes in the indicators in 2022 on military actions in Ukraine using the comparative method.

In particular, the study tracked such factors of accelerating Europe's energy transition as decarbonisation of energy production, reducing dependence or complete rejection of energy from the aggressor country's sources, and increasing renewable energy production. The materials obtained during the study also include plans for the commissioning of wind farms in Europe, the introduction of additional low-carbon heating technologies for residential and industrial facilities, and the introduction of renewable energy sources to replace fossil fuels. At the same time, since official data is currently a state secret, the scope of relocation of strategic polluting industries from the traditional eastern regions of Donbas, Kryvyi Rih, and Zaporizhzhia to the western regions was assessed using the Open-Source Intelligence (OSINT) method. Accordingly, the impact of such relocations on the environmental situation in the recipient regions was analysed.

The researchers used an open-source intelligence (OSINT) method, which involves collecting and analysing information from publicly available sources such as news, social media, government reports, and other open data sources. Using a wide range of publicly available channels, they gathered data to track the relocation of strategic polluting industries from eastern regions such as Donbas, Kryvyi Rih, and Zaporizhzhia to western regions. This data includes news, official statements, industry publications, satellite imagery, and social media posts, among others. To ensure the effectiveness of the OSINT, the researchers used specialized tools and techniques to collect, analyse and verify the data, including digital platforms, tools for extracting data from the Internet and data visualization software. In addition, ethical standards and confidentiality rules were followed, including informed consent and reliable sources to ensure the accuracy of their findings.

An empirical study was conducted using the Computer Assisted Web Interviewing (CAWI) method in the format of an online survey using a specially developed questionnaire with three questions. The questionnaire was sent to the managers of 54 large manufacturing enterprises in Ukraine, whose contacts are publicly available. The survey asked respondents to answer several questions related to the development of the circular economy in Ukraine. In particular, the competent representatives of large manufacturing companies were asked to answer the following three questions:

1. Please give a subjective assessment of the impact of full-scale hostilities on your company's resource recovery policy on a scale of 10, where "10" means continuing planned measures to implement a circular economy in production, and "1" means a complete temporary abandonment of any resource recovery programmes.
2. Describe the trends in the financing of resource-saving programmes at your enterprise in the period from 2020 to 2023 in a form convenient for you.
3. Assess the impact of digitalisation of production processes on business efficiency at this stage on a ten-point scale, where "10" means the undeniable dependence of the enterprise on modern digital technologies, and "1" means the absence of such technologies in production.

The answers to the first and third questions were processed by calculating the arithmetic mean, and the answers to the second question were subjectively analysed. Generalised conclusions were drawn for each of the three questions, which were visualised in tables for convenience. This data was made public on the condition that the answers of individual respondents were anonymised. Thus, a comprehensive assessment of the current state of development of the circular economy and the results of digitalisation in Ukraine during the war was obtained, which was compared with the current trends in the circular economy and renewable energy in the EU.

2. Results

The war in Ukraine has significantly impacted the country's infrastructure, posing challenges to progress towards a circular economy. The destruction caused by the conflict, particularly the deliberate targeting of key infrastructure, has resulted in extensive damage. For example, the occupation-induced destruction of the Kakhovka hydroelectric power station dam in June 2023 resulted in both immediate environmental repercussions and the disruption of electricity generation and distribution. This, in turn, impacted numerous sectors that depend on a consistent power supply. [4]. Additionally, the flood zone resulting from the dam's destruction engulfed critical areas, including the Kherson oil depot, river and seaports, compounding environmental hazards and impeding recovery efforts. The relocation of strategic industries from eastern regions to safer western areas, while necessary for safety reasons, has created logistical challenges and strained existing infrastructure networks [5]. The movement of industrial complexes and facilities requires robust transportation systems, including roads, railways, and ports, to facilitate the transfer of equipment and materials. However, damage to transportation infrastructure, such as roads and bridges, has hindered efficient relocation efforts, delayed the resumption of production and impeded the adoption of circular economy practices. Moreover, the disruption to water and wastewater treatment facilities exacerbates environmental concerns and poses health risks to communities [6]. The targeting of critical water infrastructure, coupled with the displacement of populations, has led to inadequate access to clean water and sanitation services, further complicating efforts to address pollution and promote sustainable water management practices. The war-related damage to infrastructure in Ukraine presents significant obstacles to advancing towards a circular economy. Rebuilding and repairing critical infrastructure, enhancing

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logistical capabilities, and ensuring access to essential services are essential steps to mitigate the impact of the conflict and resume progress towards sustainable development goals, including the adoption of circular economy principles.

One of the key indicators of the development of Ukraine's circular economy during a full-scale invasion is the rate of air emissions and water pollution. According to the State Statistics Service of Ukraine [7], the volume of discharges of polluted untreated or insufficiently treated wastewater into water bodies in 2022 was 374 million m3. At the same time, the dynamics of this indicator in previous years tend to decrease. More detailed data is provided in Table 1.

Table 1. Volumes of polluted wastewater discharged into water bodies, million cubic meters (m^3)

	2015	2016	2017	2018	2019	2020	2021	2022
Overall	875	698	997	952	737	518	542	374
Of these, by type of economic activity								
Industry	481	327	311	301	92	107	120	87
Agriculture	25	22	29	15	47	25	34	14
Trade and catering	55	51	46	46	34	0	0	0
Housing and households	308	294	608	585	564	381	382	270

Source: compiled by the authors based on State Statistics Service of Ukraine [7].

As can be seen from the table, the dynamics of the decline in polluted water discharges even before the outbreak of the full-scale war had a downward trend. The graph shows that the current downward trend in discharges began in 2018, and the 2022 figures are in line with this trend, even before the outbreak of a large-scale war. This overall decline was primarily due to the disappearance of water pollution sources in the trade and catering sectors, as well as a reduction in discharges in agriculture and households. In addition, there was a sharp decline in the amount of pollution caused by industrial production in 2019. Accordingly, in this sector, the full-scale invasion did not significantly affect the level of wastewater pollution in water bodies. The same trend continues concerning Ukraine's marine environment – the relative share of pollution discharges to the Azov and Black Seas is declining year by year and in 2022 was already less than 1% (Table 2).

Table 2. Share of polluted wastewater discharges to the marine environment in total discharges, %

Year	2015	2016	2017	2018	2019	2020	2021	2022
Main share	29.01	27.66	30.21	27.39	1.32	1.37	1.55	0.61

Source: compiled by the authors based on the State Statistics Service of Ukraine [8].

A particular negative impact of the war on Ukraine's water sector is the destruction of the Kakhovka hydroelectric power station dam by the occupation in June 2023. According to the official resource of the Ministry of Environmental Protection and Natural Resources of Ukraine "EcoZagroza" [9], the flood zone included the territories of the Kherson oil depot, river, and seaports, which are traditionally places of concentration of fuels and lubricants and hazardous waste. Given the flooded equipment of the station and the oil storage facility, which contained 465 tonnes of oil before the explosion, the destruction of the dam was a real environmental disaster, the extent of which is yet to be realised and calculated after access to the temporarily occupied territories of Kherson region is restored. Concerning air pollution, since the beginning of the full-scale invasion, the actions of the aggressor army have caused more than UAH 1 billion in damage in this area. The aforementioned EcoZagroza portal [10] reports, in particular, on more than 66 thousand ha of burnt forests, 720 thousand tonnes of oil and oil products burned because of hostilities, and almost 10 million tonnes of carbon emissions that polluted Ukraine's air from late February 2022 to November 2023. At the same time, toxic emissions reached an additional 97 tonnes, causing damage of over UAH 6 million. Although the volume of harmful emissions remains one of the most important characteristics of the effectiveness of circular economy programmes, it is worth paying attention to other components of this phenomenon. The circular economy, which is primarily aimed at the economical and efficient use of resources, is based on technological innovation, modern management, and the formation of a responsible attitude to the problem in society.

Ukraine's policy document on this path is the On Approval of the National Waste Management Strategy in Ukraine until 2030 [11], which regulates the action plan for the development of secondary resource use, considering the economic, social, and environmental interests of society. The Strategy's priority areas include household waste sorting, efficient use of agricultural waste products, and recycling and reuse of construction, repair, and demolition waste. In particular, the Strategy states that in many EU countries, the recycling rate of waste generated during construction exceeds 80%, which is a worthy benchmark for the Ukrainian circular economy. In general, the benefits of a closed-loop economy include reduced resource depletion, minimised environmental pollution, a revitalised labour market and sustainable development. The paradox is that Ukraine, having lagged far behind the leading European countries in the development of a traditional, linear economy for several reasons in previous decades, has a historic chance to catch up, as Ukrainians do not need to turn around a sluggish economic mechanism and rebuild it on new rails, but instead could rebuild circular processes almost from scratch. The key factor in this case will be the country's connectivity, mobility and variability of its logistics routes, and the President of Ukraine's national programme Big Construction [12] aims to create a competitive European hub that will be able to ensure the uninterrupted and planned movement of goods through Europe's largest country – from raw materials to finished products. It is worth noting that the resumption of this and many other ambitious programmes

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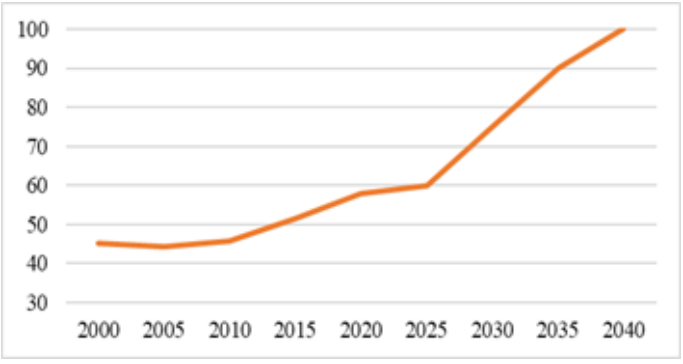
will be possible only after the victory and de-occupation of all Ukrainian territories.

In turn, Europe, with the start of the full-scale invasion, also received a powerful challenge: being virtually dependent on the aggressor country's energy supplies, the EU began to urgently build a new system of balances and counterbalances on the continent. The energy diversification programmes, which had already been calculated until 2030, were being urgently revised to meet a much shorter timeframe. In the face of rapidly rising energy prices and blackmail from the aggressor, large European industries were forced to urgently relocate their facilities to India, China, or other countries with cheap energy, thereby solving two problems at once: improving the environmental situation in Europe and making way for the latest sixth technical mode production. As a result, the outbreak of the war in Ukraine was, in a sense, a positive trigger for Europe, which made programmes to develop alternative and renewable energy sources work under stressful conditions, and the path that was planned to take 5-6 years was completed in less than a year.

In particular, there has been notable progress towards clean electricity generation, with electricity production from coal falling by a quarter since 2015. As of October 2023, 55% of electricity is generated from clean energy, including 19% from nuclear, 15% from hydropower and 16% from fast-growing wind and solar. The global gas crisis and the invasion of Ukraine have rapidly changed the landscape of the energy transition in Europe and, according to the roadmap of the 2030 Agenda, several key sustainable development goals are expected to be achieved by 2030, with a Net Zero Emissions target of a complete phase-out of fossil fuels across the continent by 2040. The planned progress of the European Union in this direction is visualised in Figures 1-3.

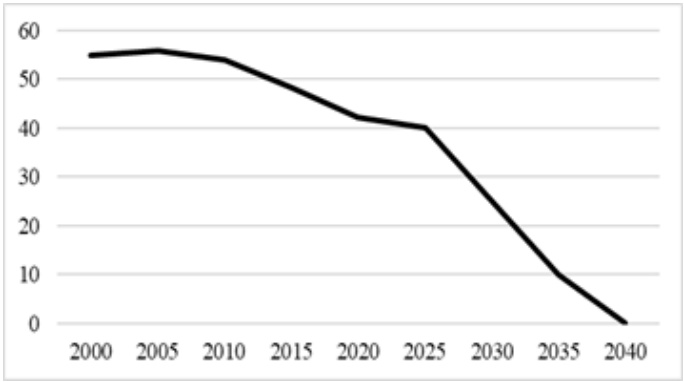
Figure 1. Actual clean energy production in the EU and forecast of dynamics, %



Source: compiled by the authors based on data from the International Climate Foundation EMBER [13].

Figure 1 illustrates the actual clean energy production in the European Union (EU) alongside the forecasted dynamics. It provides a visual representation of the percentage of electricity generated from clean energy sources over time. The data presented in the figure is compiled by the authors based on information sourced from the International Climate Foundation EMBER [13]. By tracking the trend in clean energy production, policymakers and stakeholders can assess progress towards renewable energy targets and gauge the effectiveness of energy transition initiatives.

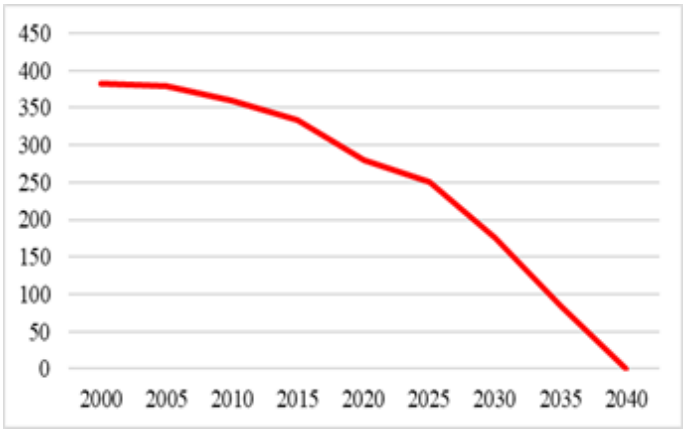
Figure 2. Actual use of fossil fuels in the EU and forecast of dynamics, %



Source: compiled by the authors based on data from the International Climate Foundation EMBER [13].

Figure 2 depicts the actual use of fossil fuels in the EU and forecasts its dynamics. It showcases the proportion of energy derived from fossil fuels, highlighting trends in reliance on these non-renewable resources over time. The data used to create this figure is sourced from the International Climate Foundation EMBER [13], providing valuable insights into the shift away from fossil fuels towards cleaner energy sources. Understanding the trajectory of fossil fuel consumption aids in developing strategies to reduce carbon emissions and mitigate environmental impacts.

Figure 3. Actual carbon emissions in the EU and forecast of dynamics, gCO_2/kWh



Source: compiled by the authors based on data from the International Climate Foundation EMBER [13].

Figure 3 presents the actual carbon emissions in the EU and forecasts its dynamics in grams of CO2 per kilowatt-hour (gCO2/kWh). It visualizes the level of carbon emissions associated with electricity generation, indicating trends in emissions intensity and environmental performance. The data utilized in this figure is

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sourced from the International Climate Foundation EMBER [13], offering policymakers and stakeholders a comprehensive view of the EU's progress towards decarbonization goals. By monitoring carbon emissions, policymakers can assess the effectiveness of emission reduction measures and tailor policies to accelerate the transition to a low-carbon economy.

Dwelling in more detail on certain aspects of Europe's new energy policy and the stages of implementation of circular economy principles on the continent, it is worth noting that, according to the International Climate Foundation EMBER [14], 19 European governments have increased their decarbonisation plans; 5 countries (Germany, France, the UK, Ireland and Denmark) have introduced additional low-carbon measures for heating and industry; Germany has declared an additional 110 GW of onshore wind power plants by 2030; the Netherlands has announced plans to double the country's offshore wind capacity over the next 7 years, and France has announced the revival of a nuclear power project. Ukraine, for its part, having only the resource of internal relocation of production facilities to manoeuvre, demonstrated efficiency in evacuating entire industrial complexes from the line of contact to safer western regions.

Before the full-scale war, the largest air pollution sources were industrial complexes in cities such as Mariupol, Kryvyi Rih, Zaporizhzhia and Dnipro, while in the capital, the main cause of carbon emissions was motor vehicles. In general, emissions from industrial enterprises accounted for up to 65% of all harmful substances released into the air. Currently, it is difficult to track the new locations of relocated large enterprises, as environmental registers are temporarily closed for security reasons. However, from some scattered and unsystematic data, it can be concluded that over the 20 months of the great war, 840 enterprises moved to the central and eastern regions as part of the relocation programme, 670 of which have already started full operations at their new locations, while others are in the process of installation and necessary documentation. This was made possible by a government programme that provided businesses with the opportunity to relocate their facilities to relatively safe regions. Most companies chose Zakarpattia region (120 companies) and Lviv region (199 companies) as their new workplace, while Odesa region (only 3 companies) and Zhytomyr region (17 companies) were the least popular. Accordingly, the environmental balance in the recipient regions has temporarily shifted to the negative side, but it will be appropriate to talk about quantitative emissions by the end of 2023.

To obtain the most objective and up-to-date picture of the problems of circular economy development in the context of war, a questionnaire was drawn up and sent by email to the management of 54 of Ukraine's largest industrial enterprises that have retained their production potential and continued their business activities, either at their original place of work or after relocation. In any case, the survey did not include enterprises that continue to operate in the temporarily occupied territories. For security reasons in wartime, the processing and publication of the data obtained was based on anonymity. Within the 10 working days specified in the mailing, 47 responses were received, 40 of which were fully completed and were taken into consideration. The distribution of scores for the first question is shown in Table 3.

Table 3. Assessment of the owners of large industries on the implementation of measures to introduce a circular economy during full-scale military operations

Score	Number of respondents who gave this score
1	1
2	0
3	3
4	4
5	5
6	4
7	5
8	6
9	5
10	7

Source: compiled by the authors.

Thus, many business leaders rate the current work on the development of the circular economy highly (7 points or more), despite the hostilities. In response to the second question, most respondents described the financing of circular economy measures in previous years at their enterprises as follows: after the forced freeze of operations in 2020 caused by COVID-19 quarantine restrictions, in 2021, additional funds were allocated for resource conservation programmes in the amount of 120% to 200% of the budget of previous years. At the end of February 2022, after the start of the full-scale invasion, all funds for recovery projects were redirected to sustainability funds, but in 2023, funding for circular economy development measures at most production facilities was resumed. As for the third and final question, the experts' opinions were distributed as follows (Table 4). As can be seen, the overwhelming majority (24 out of 40) of managers of large industrial enterprises are aware of the importance of digitalisation of their enterprises and give the maximum (9-10 points) assessment of the impact of digital technologies on their work.

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Table 4. Assessment of large-scale production owners on the impact of digitalisation of production processes on business efficiency during full-scale hostilities

Score	Number of respondents who gave this score
1	1
2	0
3	0
4	0
5	7
6	1
7	4
8	3
9	13
10	11

Source: compiled by the authors.

Thus, the results of the analytical, statistical, and empirical studies conducted converge on a single conclusion: despite the war and daily losses, Ukraine remains faithful to the chosen path of implementing resource-saving technologies and circular economy values.In the context of the war in Ukraine, the study of circular economy development has revealed several key findings. The war has caused serious damage to the country's infrastructure, including energy facilities, which has complicated progress towards a circular economy and increased environmental risks due to the destruction of the Kakhovka hydroelectric power plant and the flooding of key facilities. Political, economic, and environmental factors have been the focus of the study, which indicates their importance for the further development of the circular economy.Despite the military conflict, Ukraine continues to move forward with the implementation of circular practices, which demonstrates the country's resilience and commitment to the chosen path. The responses to the questionnaire from the heads of large industrial enterprises confirm the high appreciation of the work on the development of the circular economy during the military actions, which emphasizes the importance of financing and digitalization for sustainable development in times of crisis.

3. Discussion

Given that the circular economy is one of the important components of the concept of sustainable development, it is worth considering it from a broader, global perspective. Since there will be a demand to restore production and infrastructure after the war is over, it is worth considering the global experience in this area and analyzing the work of the global scientific community.

Comparative analysis with countries that have implemented circular economy principles during periods of conflict or instability can provide valuable insights into the challenges and opportunities faced by Ukraine in its pursuit of sustainable development amid wartime conditions. Rwanda provides an interesting case study of implementing circular economy principles amidst post-conflict reconstruction efforts. Following the Rwandan genocide in 1994, the country faced significant challenges in rebuilding its economy and infrastructure [6]. However, Rwanda has since made remarkable progress in promoting sustainability and circularity. The government has implemented policies to promote waste management, renewable energy, and green technologies. Despite the lingering effects of conflict, Rwanda's commitment to sustainability has contributed to its economic growth and development[8].

Colombia has faced decades of armed conflict and instability due to internal conflicts involving guerrilla groups, paramilitary forces, and drug cartels. Despite these challenges, Colombia has made strides in adopting circular economy practices, particularly in the areas of waste management and renewable energy. The government has implemented initiatives to promote recycling, reduce waste generation, and invest in clean energy projects. Colombia's experience demonstrates that even in the midst of conflict, efforts to embrace circular economy principles can contribute to environmental sustainability and economic resilience [15].

Lebanon has faced political turmoil, civil unrest, and armed conflicts for decades, resulting in significant social, economic, and environmental challenges. Despite these obstacles, Lebanon has recognized the importance of transitioning towards a circular economy to address environmental degradation and resource scarcity. The country has initiated projects to promote sustainable agriculture, water conservation, and renewable energy development. However, ongoing political instability and economic crises have posed challenges to the effective implementation of circular economy initiatives.

The Israeli-Palestinian conflict has resulted in decades of political tension, violence, and territorial disputes, impacting the socioeconomic development of both sides. Despite the protracted conflict, efforts to promote sustainability and circularity have emerged in both Israel and Palestine. In Israel, initiatives focus on water conservation, renewable energy, and innovation in green technologies [16]. Similarly, Palestinian territories have seen projects aimed at promoting sustainable agriculture, waste management, and renewable energy adoption. However, the conflict's complexities and resource constraints continue to pose challenges to the widespread adoption of circular economy practices in the region. Comparing Ukraine's experience with these examples highlights the multifaceted nature of implementing circular economy principles during periods of conflict or instability. While challenges such as damaged infrastructure, resource constraints, and political uncertainty are prevalent, there are also opportunities for innovation, resilience, and sustainable development. By learning from the experiences of other countries and leveraging international support, Ukraine can navigate the complexities of wartime conditions and advance its circular economy agenda towards a more sustainable future.

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Suchek et al. [15], based on a sample of more than a hundred scientific articles collected from various databases, identified several thematic groups – growing circular small and medium-sized enterprises, start-up circular firms and start-ups, social entrepreneurship, and the ecosystem supporting circular entrepreneurship. Having studied specific examples of the circular economy, the authors propose their agenda for future research and a conceptual model of the entrepreneurial process as a starting point for the further development and expansion of resource-saving enterprises. The managers of the large enterprises interviewed for this study also demonstrated their interest. The mechanisms for creating strategic stocks in circular economy industries, which were very important during martial law, were the subject of the work of Kuzior et al. [16]. They provided a theoretical overview of the concept of a circular economy, its impact on business and environmental protection, and proposed algorithms for creating the strategic potential of an enterprise in a crisis. The balance of structural elements and rationality proposed by the authors may be useful for the Ukrainian economy, especially given that the study found a lack of structured theoretical information.

Dudziak et al. [17], in turn, explored the problems of the circular economy in the context of food waste and responsible waste sorting, which was also mentioned in this paper. Emphasizing that the topic of waste is simultaneously relevant in terms of ecology, economy and society, the authors conducted a consumer survey among residents of Eastern Poland and determined social attitudes towards the problem. After processing the results using cluster analysis, it was proved that consumers are aware of the dilemma of excessive consumption and waste sorting, but their level of responsibility is not yet sufficient to consider the problem solved, which is also typical for Ukrainian society. The importance of empirical research in the field of sustainable production and distribution systems for accelerating the transition to a circular economy, one of which was conducted in this paper, was discussed by Genovese et al. [18]. The authors emphasized the need to conduct empirical research on circular supply chains in the context of socially sustainable and economically balanced production and logistics systems. They suggested several important areas for future research in this area.

Another article devoted to the main tools for measuring the circular economy in general and the food system, in particular, is the work of Fassio and Chirilli [19], which aimed to analyze indicators, methods and best practices of the circular economy, highlighting critical points and possible gaps. The work demonstrated that most traditional indicators, which were also evident during this work, focus only on assessing the final stage of the product life cycle, without paying attention to the nutrient cycles in food systems and the circular bioeconomy. Changing the focus to the object of study would, in the authors' opinion, significantly improve the measurement technique in this area. Marques and Teixeira [20], in search of reducing the severity of the problem of overexploitation of natural resources, assessed the state of municipal waste management in the circular economy. Investigating the effectiveness of municipal waste management in the European Union on the example of 24 countries, the authors noted a noticeable gap in this issue between Northern and Southern Europe and recommended that policymakers focus on environmental awareness through education, raising the human development index, and not separating economic growth from environmental damage. Given certain problems in Ukrainian society with the culture of waste disposal that were identified in the course of this study, these recommendations will be valid for Ukrainian policymakers as well.

Returning to the issue of European medium-term planning programsanalyzed in this article, it is worth mentioning the work on this topic by Širá et al. [21]. Their study aimed to determine the state of the circular economy in the agricultural sector of the EU-27 countries in the context of the 2030 Agenda. The study results showed heterogeneity between EU countries and the lack of a link between agricultural waste management and a country's GDP. Accordingly, the 2030 Agenda should be revised to draw interim conclusions and make the necessary adjustments. Another study was conducted byMarković et al. [22] to assess and compare the effectiveness of waste management at the European Union level. Creating a generalized index based on Eurostat data, the authors found that Western European countries demonstrate the best results in establishing good practices in household waste management (the Netherlands, Austria, Belgium), while countries that joined the EU much later (Bulgaria, Romania, Croatia, Poland) have the lowest values of the waste management culture index. For Ukraine, which is only on its way to the EU and, as noted, does not currently provide the required level of recycling, this fact should be a signal to accelerate its waste management practices. Rodríguez-Antón et al. [23], using the empirical tools also used in this paper, set out to answer two relevant questions about sustainable development in the EU – whether the goals set out in the 2030 Agenda can be considered homogeneous for all countries and whether there are significant correlations between the implementation of the circular economy in the EU and the sustainable development goals. Using correlation analysis, exploratory factor analysis, and cluster analysis, the behavior of European countries was determined as not homogeneous, with significant interrelationships between the circular economy and the sustainable development goals in the EU environmental programs. As noted in the course of this paper, the national economies of EU countries do differ in their approach to resource-saving measures.

Modern technologies for resource conservation are impossible without the digitalization of processes, as this article has shown. A similar point is made by Bressanelli et al. [24], arguing that companies that use IoT and Big Data technologies in their circular economy projects potentially increase their sustainability without compromising the competitiveness of their value chains. Another point related to the informatization of innovative technologies to support growth trends in the circular economy was made by Kuzior et al. [25] – digitalization can help solve a range of macroeconomic problems such as unemployment,

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inflation, and lack of resources. At the same time, there is also criticism of the circular economy concept – Corvellec et al. [26] argue that it has blurred boundaries, and unclear theoretical foundations, and its implementation often faces moral factors. Moreover, according to the authors, the circular economy is based on an ideological program dominated by technical and economic calculations, which makes an uncertain contribution to sustainability and depoliticizes sustainable growth. However, this study did not identify such shortcomings of the circular economy ideology.

Martial law, which has become an important factor in the modern Ukrainian economy, the impact of which was studied in this paper, has also been studied by foreign experts. In particular, Nygaard [27] and Ilchuk et al. [28] analyzed Europe's resource dependence on totalitarian and aggressive countries and concluded that the circular economy reduces geopolitical risks but does not eliminate them. Ukraine's experience confirms this hypothesis. Chowdhury et al. [29] and Matsybora [30] also studying the impact of the war in Ukraine on the energy and food crises, state that not only those Ukrainian regions where active hostilities are taking place but also the rest of the country have suffered negative environmental impacts. It is noteworthy that the study also found a deterioration in environmental conditions in the regions where enterprises were relocated. Nevertheless, the authors present their strategy for post-war ecosystem restoration, which prioritizes circular economy tools [31, 32].

Comparing the above conclusions of the world scientific community with the results obtained in the course of this study, it is worth noting the predominantly similar assessment of energy blackmail by the aggressor and the similarity of plans for the post-war reconstruction of Ukraine.The report on the development of the circular economy in the context of the war in Ukraine raises important questions about the impact of the conflict on the country's sustainable development. A comparative analysis with countries that have implemented circular economy principles during times of conflict or instability provides valuable lessons and opportunities for Ukraine. In particular, the experience of Rwanda, Colombia, Lebanon, and Israel and Palestine shows that, despite the challenges, the adoption of circular economy principles contributes to sustainable development and economic resilience. The analysis of scientific research shows a growing interest in circular economy issues and the importance of digitalization for process efficiency. These findings provide an opportunity to develop strategies for the recovery and sustainable development of Ukraine during the war.

Conclusions

The modern world is facing many challenges, but until recently, the international project on sustainable development goals was formulating a plan to overcome key problems such as global hunger, the energy crisis, and air and water pollution. However, the unmotivated and unjust war of aggression unleashed by Russia against Ukraine in 2014, which escalated into a full-scale invasion in February 2022, has significantly changed all existing plans.

In the context of the military conflict in Ukraine, the study of circular economy development has revealed several key findings. First, the war has severely damaged the country's infrastructure, including energy facilities, which has complicated progress towards a circular economy and increased environmental risks. The destruction of the hydroelectric power plant at the Kakhovka Dam and the flooding of key facilities have had serious consequences for the environment and infrastructure. Political, economic, and environmental factors were key in the study, emphasizing their importance for the further development of the circular economy.

Despite the military conflict, Ukraine continues to make progress in implementing circular practices, which demonstrates the country's resilience and commitment to the chosen path. The results of the survey of managers of large industrial enterprises confirm the high appreciation of the work on the development of the circular economy even during the period of military operations, which emphasizes the importance of financing and digitalization for sustainable development in times of crisis.

European countries, which were forced to quickly revise their energy security programs, were able to redistribute available resources and prevent large-scale disasters in the gas market during the most critical heating season of 2022-2023. Thanks to this mobilization, the EU is now planning a complete phase-out of carbon emissions and the use of fossil fuels even earlier than it was planned a decade ago. Ukraine, in turn, also survived the first, most difficult months of an undeclared full-scale war and was able to resume circular economy development programs within a year. Despite the necessity for numerous large-scale manufacturing enterprises to relocate to safer regions, Ukraine persists in the advancement of environmental protection and energy-efficient policies. Ongoing military operations inflict substantial environmental damage daily, encompassing the occupation of arable land in the South, contamination of the eastern regions due to combustion by-products and rocket explosions, and extensive mining along the northern borders. Nevertheless, post-war reconstruction efforts will facilitate the establishment of new infrastructure and businesses, adhering to the principles of circular economy, thereby obviating the need to dismantle the preceding obsolete linear system.

This approach will be a competitive advantage for the largest European country, which will be able to demonstrate its leadership in the systematic implementation of a closed-loop economy. The calculation of the economic benefits of such programs in the de-occupied territories, including Crimea, may be the subject of a future study.

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