Analytic Hierarchy Process of Circular Economy Factors Influencing the Activities of Open Socio-Economic Systems: Problems and Prospects for Their Solution

Yaroslav Pushak[1], Andryi Zachepa[2], Taras Shyra[3], Olga Poplavska[4] and Iryna Bezpalko[5]

Abstract

The main purpose of the article is to construct the author's approach to the implementation of tactical measures to respond to the increased influence of circular economy factors. The object of the study is the open socio-economic systems of Ukraine. The scientific task is to modify the use of hierarchy analysis to construct a new modeling approach. The research methodology involves the use of the analytical hierarchy process method to highlight the most influential factors of the circular economy in open socio-economic systems. At the same time, the selection of factors occurred through the method of expert analysis and the Delphi method. Ukrainian enterprises were chosen as an example of open socio-economic systems. Deepening the theoretical foundations of the modern understanding of the circular economy with the generalization of analytical materials that determine the level of basic indicators and the significance of the impact of military operations have created the necessary basis for a holistic vision of this new economic model. As a result of the study, a conceptual approach was formed, which consists in using the hierarchy analysis method to streamline the influence of circular economy factors, which provides maximum flexibility in the implementation of measures to achieve the strategic goals of enterprises. The calculations carried out provided the formation of the necessary information basis for planning and implementing tactical measures to respond to the influence of circular economy factors.

Keywords: *Analytic Hierarchy Process, Open Socio-Economic Systems, Enterprises, Martial Law, Circular Economy, Hierarchical Ordering, AHP*

INTRODUCTION

The circular economy is an innovative economic model designed to extend the lifecycle of resources, reduce waste, and minimize environmental impact. Unlike the traditional linear economy, which follows a 'take-make-dispose' approach, the circular economy emphasizes reusing, repairing, refurbishing, and recycling existing materials and products. This approach aims to keep resources in use for as long as possible, extract the maximum value from them while in use, and recover and regenerate products and materials at the end of their service life. This shift from linear consumption reduces the demand for extraction of new resources, thereby decreasing environmental degradation and pollution.

The impact of the circular economy on the environment is profoundly positive. By promoting the reuse and recycling of materials, the circular economy significantly reduces waste generation. For example, when products like electronics or plastics are recycled, they re-enter the production cycle rather than ending up in landfills or incinerators. This not only lessens the volume of waste but also cuts down on methane emissions from landfills and reduces the need for incineration, which emits carbon dioxide and other pollutants. Furthermore, the circular economy reduces the consumption of raw materials, which in turn lowers the energy expenditure and greenhouse gas emissions associated with manufacturing and processing new materials. Another critical aspect of the circular economy is its focus on sustainable design and innovation. Products are designed for durability, ease of maintenance, and recyclability, which supports the environment by reducing the need to constantly produce new products. This design philosophy encourages manufacturers to consider the full lifecycle impact of their products, leading to innovations that replace scarce or harmful materials with more sustainable

---

[1] Lviv State University of Internal Affairs, Lviv, Ukraine

[2] Ukrainian Academy of Printing, Lviv, Ukraine

[3] Ukrainian Academy of Printing, Lviv, Ukraine; E-mail: sulo1@ukr.net
[4] Khmelnytskyi National University, Khmelnytskyi, Ukraine

[5] Ukrainian Academy of Printing, Lviv, Ukraine

alternatives. As a result, these practices can significantly reduce the ecological footprint of production processes, including reductions in water usage, energy consumption, and pollution.

High rates of economic development, caused by an increase in the planet's population and the need to meet the needs of each individual beyond the basic level, have provoked the need for greater use of natural resources, which is already a difficult task to accomplish in current conditions due to a decrease in the efficiency of the reproductive mechanism. The question is no longer about the ability of subsequent generations to use natural resources, but a growing discrepancy for today's inhabitants of the planet between the need and the existing resource base. Consequently, there is a need to transition from the outdated model of the "linear economy", which is based on the processes of production, use and further transformation into waste of an unlimited amount of natural resources, in favor of the "circular economy", which today relies on innovative solutions to save raw materials, in particularly through reuse, waste reduction and reduced environmental impact. The idea of a "circular economy" has deep roots, as similar principles were followed in the production of agricultural products in pre-industrial society, when waste and the results of food consumption were used to prepare the soil for the next growing season. In modern conditions, we are talking about creating a technologically complex product, but the rational use of natural resources and consumption should dominate the interests of individuals. An additional argument in favor of wider implementation of the principles of the circular economy was COVID-19 due to the need to implement economic recovery, which is impossible within the framework of the "linear economy" due to the insufficient resource base that can be expanded, but on the basis of deepening waste recycling and reuse . In Ukraine, until February 2022, the importance of progress in the transition to a circular economy was recognized at the declarative level, but practical steps were limited due to the difficult economic situation. Increased war anger on the part of the russian federation has reduced the priority of the transition to a circular economy. Today, massive facts of environmental damage are being recorded, but in the future, this situation can be used for faster progress thanks to international support and the use of best practices for post-war reconstruction, which requires the premature creation of the necessary theoretical basis and the study of best practices, in particular from EU countries.

The concept of "circular economy" is new, multifaceted and important - changing under the pressure of a significant number of factors accompanying the activities of modern man, when not only does he influence the environment, but also the feedback from restrictions and new threats increases. in the global dimension The intensity of the transition to a circular economy differs in the conditions of each country. The previously existing dominance in the understanding of this economic model of environmental fundamentals has today been replaced by an equally significant need to achieve economic and social effect. Countries leading economic development see in the circular economy new opportunities to strengthen their competitive positions through the rational use of natural resources, responsible consumption of the total social product, filling the production cycle with recyclable materials, and creating new jobs in the field of waste recycling, which is possible due to higher innovative activity commodity producers. Ukraine has made little progress in the development of a circular economy over the past decade, but the current situation, burdened by large-scale military operations, creates opportunities for rapid transformation as part of the future stage of post-war recovery.

In accordance with current forecasts, the population of our planet in 2050 will approach 9.6 billion people, the existence of which, by current standards, cannot be met. This assumption is based on the fact that over the past ten years the volume of use of natural resources has increased significantly, when their restoration in the natural environment does not cover even 70%. The reasons for this: constantly growing volumes of extraction of natural resources, low production efficiency due to high material and energy intensity, increased emissions into the environment, irresponsible use and disposal to landfills, the size and condition of which negatively affect the quality of life, provoking the spread of chronic diseases. Awareness of the importance of solving environmental and economic problems occurs in every country, but the means differ according to the stage and trends of development. Economically developed countries are striving to reduce the technological burden on the environment, using the results of the fourth industrial revolution, when the main resource is information and knowledge. Countries with a low level of development, while continuing to be resource-oriented in the formation of national economies, are struggling with pressing problems of poverty, hunger and low levels of

education of the population. Consequently, there is an imbalance that makes it impossible to achieve real progress in maintaining a balance between the needs of humanity and the available natural resources throughout the planet. In order to form a joint vector of action for countries with different levels of development, at the 70th session of the UN General Assembly in 2015, 17 sustainable development goals were formed and adopted to achieve them. The circular economy target has a twelfth goal called "Responsible Consumption and Production."

The results of assessing the level of development of the circular economy made it possible to identify significant national differences in investment opportunities, volumes of waste generation, and the ability to recycle and effectively use them. At the same time, best practices need careful study and adaptation to the conditions of other countries, which is also relevant for Ukraine. Thus, as noted above, Ukraine ranks third in Europe in terms of volumes of food waste, the main share of which is occupied by those generated during the production of sugar and processing of grain crops with subsequent disposal, although borrowing technology from other countries would make it possible to process them into fertilizers.

Comparing the results of introducing a circular economy in the EU and Ukraine is impossible today in the absence of a common approach. Therefore, we made such a comparison based on individual key indicators. Based on data from the State Statistics Service of Ukraine. A general idea of waste generation and management is formed on the basis of the indicators presented in Table. 1.

Table 1 Volumes of waste generation and management in Ukraine, thousand tons

	Waste generated	Waste utilized	Waste incinerated	Waste removed to specially designated places or facilities	Total waste volume accumulated during exploitation in the specially designated places or facilities (managed dump-sites)
2010	422549,9	144866,6	1056,8	311649,0	13219983,9
2015	312267,6	92463,7	1134,7	152295,0	12505915,8
2020	462373,5	100524,6	1008,0	275985,3	15635259,6

We did not go into detail about each individual year, but took into account the last decade, which allows us to make the following important clarifications:

- the total volume of waste generation did not change significantly when the population decreased. For example, in 1990, the population of Ukraine was 51,838.2 thousand people, while in 2010 it was 45,962.9, in 2015 it was 42,929.3, and in 2020 it was 41,902.4. That is, there are opposite trends in 2010 and 2020: population reduction with increasing waste, which indicates a decline in the culture of handling natural resources with the subsequent increase in pressure on the natural environment from the side of the population; - it is not given in the table, but we found out that the amount of waste generated by the activities of enterprises has a clear tendency to decrease within the specified period (in thousand tons in 2010 - 1389.1; in 2015 - 587, 3; 2020 – 532.0). Interesting dynamics prompted us to determine the dynamics over a longer period: in 1995, this indicator was (thousand tons) 3562.9, in 2000 – 2613.2, in 2005 – 2411.8. At first glance, the positive dynamics are not related to progress in the generation of waste at industrial enterprises, but solely due to a decrease in the intensity of enterprise activity. The main part of large and medium-sized enterprises with a complex technological cycle ceased operations, and hundreds of thousands of small producers were formed on their basis, whose products satisfy the individual needs of a limited circle of consumers, while not generating a significant amount of waste. That is, such a dynamic should be perceived in two ways - less waste, but the deterioration of the economic situation and the release of the workforce with the growth of labor migration and the strengthening of the social crisis; - the increase in the amount of accumulated waste is related to the state policy, which is not focused on creating processing facilities, but mostly on expanding the boundaries of existing landfills.

The generalizations made are confirmed by indicators of household and other waste management (Household and similar waste management) per person (Fig. 1).
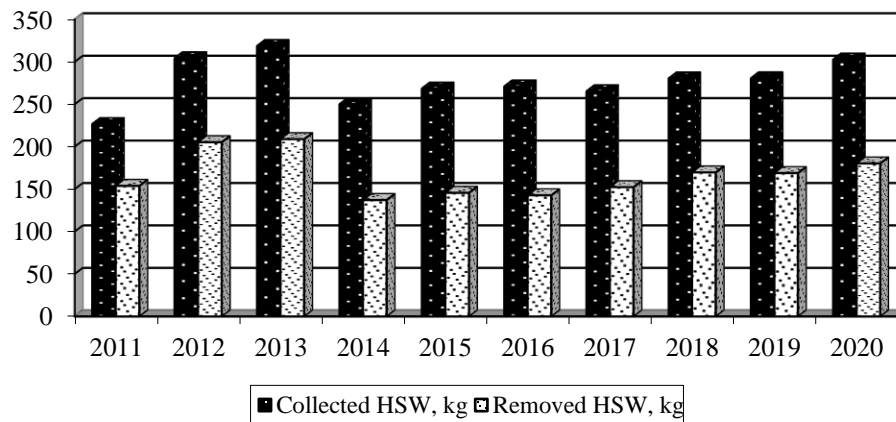
Figure 1 Handling of household and similar waste per person, kg

The data presented graphically indicates the fact that the majority of waste generated by the population (in 2020 - 59.5%) is subject to burial, with only 40.6% in specially equipped landfills, and others - in spontaneous ones with subsequent damage . natural environment.

The structure of the article includes a review of the literature, a presentation of the main research methods, their application to the results, a discussion of the results and conclusions. The main purpose of the article is to construct the author's approach to the implementation of tactical measures to respond to the increased influence of circular economy factors. The object of the study is the open socio-economic systems of Ukraine.

LITERATURE REVIEW

Cerya, E., Idris, I., and Marta, J. (2023) provide an essential analysis of the factors influencing the adoption of circular economy principles among Micro and Small Manufacturing Enterprises in West Sumatera. Their study identifies significant enablers such as regulatory support and technological innovation, alongside barriers like limited financial resources and lack of consumer awareness. These insights are critical in understanding the micro-level application of circular economy principles and their scalability in broader contexts. Kryshtanovych et al. (2020) provide a comprehensive evaluation of the implementation of circular economy practices across European Union countries. Their study assesses these practices within the frame of sustainable development, offering crucial insights into the effectiveness of policy measures and industrial practices that align with circular economy principles. The researchers highlight significant variations in adoption levels among countries, attributing these differences to economic, cultural, and regulatory factors which shape the pace and effectiveness of circular economy implementation .

Muafi (2021) explores the integration of organizational culture and strategic management within the context of the circular economy. The study specifically looks at the interplay between green culture, green strategy, and green intellectual capital, and how these elements influence the effectiveness of circular economy practices. Muafi introduces the concept of green intellectual capital as a moderating variable that enhances the relationship between green culture and the strategic implementation of circular economy principles, thus contributing to a more sustainable organizational and environmental outcome. Ghisellini, Cialani, and Ulgiati (2016) offer a broader perspective by reviewing the circular economy as a transformative shift towards a balanced interplay between environmental sustainability and economic systems. Their analysis synthesizes various models and approaches that have been proposed to facilitate this transition. The authors argue for a systemic shift that includes technological innovation, policy reforms, and changes in consumer behavior as integral components of a successful circular economy .

In the domain of eco-innovation, Stankevičienė and Nikanorova (2020) investigate its role as a crucial pillar for the sustainable development of the circular economy. Their research underscores the importance of eco-innovative approaches in enabling businesses to transition towards more sustainable operations. The findings suggest that eco-innovation not only supports environmental goals but also offers competitive advantages to businesses adopting these practices . Lastly, Vanhamaki et al. (2019) examine the role of bio-based strategies within the circular economy, focusing on their incorporation in European national and regional strategies. Their study emphasizes the potential of bio-based approaches to significantly contribute to circular economy goals, particularly through reducing dependency on non-renewable resources and minimizing ecological footprints. The researchers provide examples from various European strategies that integrate bio-based elements, illustrating a growing recognition of their importance in circular economy initiatives.

The integration of the Analytic Hierarchy Process (AHP) into the circular economy and socio-economic systems has been thoroughly investigated over recent decades. AHP's utility in providing structured decision-making frameworks is well-documented, offering a systematic approach for evaluating factors that influence various sectors, including open socio-economic systems. This literature review explores significant contributions to the field, which underpin the application of AHP in analyzing and solving complex decisions within circular economies. Makkulawu et al. (2023) provide a comprehensive review on integrating Geographic Information Systems (GIS) with AHP to enhance decision-making processes. They argue that the synergy between AHP and GIS facilitates a more informed decision-making framework by spatially analyzing the data, which is crucial for planning and implementing circular economy strategies. The precision and accessibility of GIS, combined with the multi-criteria decision-making capability of AHP, enable stakeholders to visualize potential outcomes and impacts more effectively, thereby supporting sustainable development initiatives within open socio-economic systems.

The foundational work by Saaty, the developer of AHP, alongside various collaborators, continually emphasizes the flexibility and adaptability of AHP to group decision-making scenarios. Saaty and Peniwati (2007) explore the nuances of drawing out and reconciling differences within group settings, an essential aspect of managing circular economy initiatives involving multiple stakeholders . Furthermore, Saaty and Shang (2007) discuss the significance of considering both the head-count and the intensity of preferences in group decision-making processes, highlighting the method's adaptability to different situational contexts. Barić and Pižeta (2018) demonstrate the application of AHP in designing safer level crossings, showcasing the model's utility in infrastructure safety and security engineering. This research underscores the versatility of AHP in addressing safety-related decisions in public infrastructure projects, aligning closely with the principles of circular economies where sustainability and safety are paramount.

The early adaptation and enhancement of AHP are evident in the work by Donegan et al. (1992), who introduced new approaches to the methodology to better suit complex decision-making scenarios. This adaptation has been crucial in expanding the applications of AHP beyond its initial academic settings into real-world applications, including those affecting open socio-economic systems. Yang (2020) analyzes the impact of open residential communities on road traffic using AHP integrated with fuzzy theory, illustrating how AHP can handle uncertainties and imprecise information prevalent in urban planning and management. This study is particularly relevant to circular economy considerations, where urban systems must be optimized for both efficiency and minimal environmental impact.

Finally, Mu (2006) provides a unified framework using AHP for site selection and business forecasting. This application is integral to strategic planning within businesses, especially those operating within the circular economy. By ensuring optimal site selection and accurate forecasting, businesses can minimize environmental impact and enhance economic sustainability.

As a result of the conducted research, we singled out the most significant gaps in modern literature (Table 2).

Table 2 The main gaps in Literature review

Gaps	Characteristics
Lack of Region-Specific Models for Circular Economy	Much of the existing literature on circular economy models tends to be global or based on specific developed countries. There appears to be a gap in literature specifically tailored to the unique challenges and opportunities presented by countries like Ukraine, which may face distinct

	political, economic, and social dynamics. This includes the impact of ongoing military conflicts on the economy and how these affect the implementation of circular economy principles
Integration of Circular Economy and Conflict Impact	There is limited research that explicitly examines the intersection of circular economy practices with the impacts of military operations. The unique context of a country under conflict can significantly alter the priorities and feasibility of implementing circular economy strategies. More research might be needed to understand how circular economy initiatives can be adapted to contexts where the basic economic and social infrastructures are compromised
Methodological Innovations in Assessing Economic Models	The use of methods like the analytical hierarchy process combined with the Delphi method for expert analysis in circular economy studies is not extensively covered in existing research. There is a potential gap in exploring how these methodologies can be effectively utilized to evaluate and prioritize economic factors in open socio-economic systems, particularly those undergoing significant disruptions like Ukraine. Further research could enhance understanding of how these methodologies can be modified or optimized for better decision-making in complex environments

Exploring these gaps could contribute significantly to both the academic discourse and practical implementations of circular economy strategies in similar socio-economic contexts. The scientific task is to modify the use of hierarchy analysis to construct a new modeling approach.

METHODOLOGY

At the core of our methodology is the Analytical Hierarchy Process (AHP), a decision-making tool that helps in dealing with complex decisions. By breaking down the decision problem into a hierarchy of more easily comprehended sub-problems, each of which can be analyzed independently, the AHP assists in capturing both subjective and objective aspects of a decision. In this case, the sub-problems relate to various factors of the circular economy which affect the operations and sustainability of open socio-economic systems. Thomas L. Saaty, the creator of AHP, significantly contributed to operations research and decision-making through his development of this method. His work enabled a systematic, quantitative approach to complex decision-making where subjective judgments needed to be quantified. Saaty's development of the consistency index and ratio was also pivotal, as it introduced a way to measure and thereby improve the reliability of the decision-making process.

AHP has been used effectively in diverse fields. For example, in business, it can help determine the best location for a new facility by evaluating potential sites across multiple criteria such as cost, accessibility, and potential for growth. In public policy, it can be used to prioritize projects based on various indicators of community benefit. In technology, it might help decide between software solutions, evaluating them across a range of technical and financial criteria. AHP is praised for its flexibility, rigor, and the clarity it brings to decision-making processes. It facilitates discussions among decision-makers by helping them understand the problem structure and the impact of their judgments on the overall decision, ultimately leading to more informed and acceptable decisions.

Expert analysis involved consulting with seasoned professionals within the industry to gather insights based on their experience and understanding of the sector. This provided a solid foundation of primary data which is critical in such explorative studies. Concurrently, the Delphi method was implemented as a systematic, interactive forecasting method which relies on a panel of independent experts answering questionnaires in two or more rounds. After each round, a facilitator provides an anonymous summary of the experts' forecasts and reasons for their judgments. This feedback loop continues until the range of the answers converges towards a consensus, thus ensuring that the factors identified are reflective of collective intelligence and are not biased by any single expert's perspective.

Our selection of Ukrainian enterprises as the context for the study not only responds to the geopolitical and economic specificity required for such an analysis but also allows for a detailed examination of how external shocks, such as military operations, influence the adoption and implementation of circular economy practices. Through this localized focus, the research deepens the theoretical underpinnings of the circular economy by analyzing how these enterprises adapt to significant external pressures.

The study's conceptual approach was developed through the AHP, organizing the various identified factors of the circular economy in a hierarchical structure that prioritizes them according to their level of impact on

strategic goals. This hierarchical structure not only aids in understanding the relative importance of each factor but also provides a clear pathway for tactical decision-making aimed at enhancing resilience and sustainability.

The research carried out is aimed at forming a holistic vision of the circular economy, which became possible thanks to a combination of intelligence on the historical stages of building the theoretical basis of this new economic model, identification and critical analysis of key indicators of different countries and taking into account the significance of the influence of such factors as military actions that dominate today in relation to economic, political and social processes in Ukraine.

RESEARCH RESULTS

The development of the circular economy is hampered by the presence of a number of barriers, which are different in content in each country, but among them there are also common ones, which include:

F1. Regulatory and Policy Inconsistencies. In many countries, existing laws and regulations have not caught up with the principles of the circular economy. This leads to inconsistencies where policies may inadvertently support linear, rather than circular, practices. Regulatory gaps, conflicting policies across different levels of government, and slow legislative processes can impede the adoption of circular economy practices.

F2. Technological Challenges. The lack of necessary technology for efficient recycling, remanufacturing, and redesigning products to fit a circular model is a major obstacle. Additionally, some regions may lack the infrastructure needed to support such technologies, which can hinder the circular transformation.

F3. Market Dynamics and Consumer Behavior. Consumer awareness and demand for circular products often lag behind, which can slow down the market's transition. There is also a lack of established markets for secondary materials and recycled products, making it difficult for companies to find profitable avenues for their circular economy initiatives.

F4. Cultural and Behavioral Resistance. Cultural norms and consumer habits deeply influence the success of circular economy strategies. Resistance to changes in consumption patterns, such as the preference for new over reused or recycled products, poses a significant challenge.

F5. Supply Chain Complexity. The circular economy requires a systemic change in how supply chains operate, moving away from linear supply models to more integrated, closed-loop systems. Managing such complexity, especially in global supply chains, can be daunting for many businesses.

F6. Economic and Financial Hurdles. The initial cost of transitioning to circular economy models can be high, deterring businesses from adopting sustainable practices. The lack of financial incentives, such as subsidies or tax breaks for circular economy activities, and the challenging economic viability of recycling and reuse in markets dominated by cheaper virgin materials, are significant barriers.

F7. Lack of Information and Transparency. There is often a significant gap in the availability and accessibility of information regarding the lifecycle impacts of products and materials. Without adequate data, companies and consumers cannot make informed decisions that support circular economy principles.

F8. Skills and Knowledge Gaps. As the circular economy is still a relatively new concept, there is a significant gap in expertise and skills needed to implement it effectively. This includes designing for disassembly, materials science for better recycling, and systems thinking in business and policy-making.

Together they will form a set:$F=\{F1;F2;F3;F4;F5;F6;F7;F8\}$.

Let's move on to the actual construction of the analytical hierarchy process model, which will include 4 levels. The top goal will be set: - Implementation of a new enterprise development strategy. To do this, the second level of the hierarchy involves the implementation of tactical measures that will be based on how the factors influencing the circular economy change. Consequently, the third level is cases of changes in the influence of factors of the circular economy: critical increase in influence (++); slight gain (+); no changes (+/-); significant reduction in influence (--); slight decrease in impact (-). The factors of the circular economy identified by us and the experts are also found at the last level (Fig. 2).
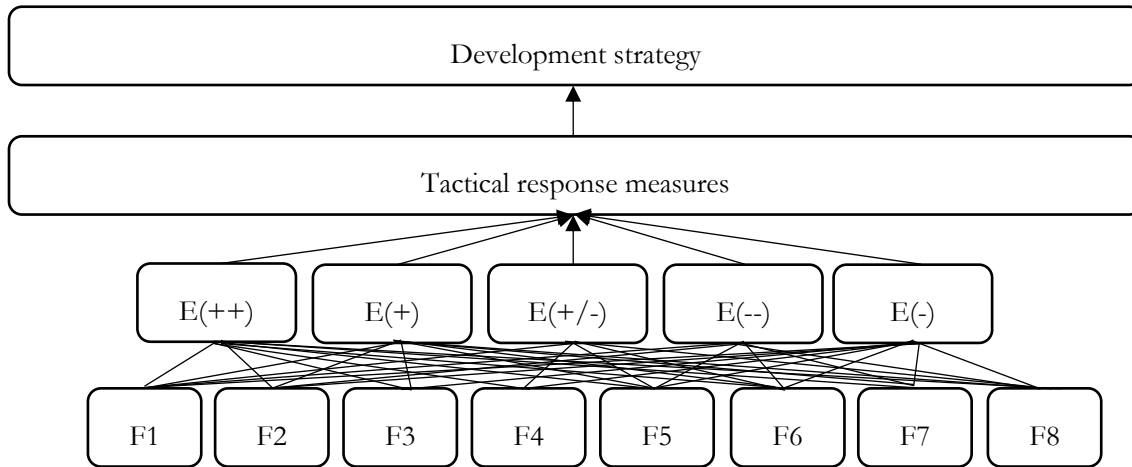
Figure 2 The analytical hierarchy process model

Next, we proceed to a direct assessment through a pairwise comparison.

The initial step will be to directly evaluate the alternatives themselves; for this we carried out calculations that will contribute to the construction of the paired comparison matrices themselves. Let's present all the key formulas for calculating matrices of paired comparisons and their levels of inconsistency in a tabular format (Table 3).

Table 3. The main formulas we use in our article

Number	Characteristics
(1)	$$\frac{n*(n-1)}{2}$$ where n is the number of criteria at one level
(2)	$$n*\frac{m*(m-1)}{2}$$ where m is the number of alternatives, that is, it is necessary to compare 140 development options
(3)	$Sj=\sum_{i-1}^{n} aij$ where Sj is the sum of the j column, n is the number of rows in the matrix, aij is the matrix element at the intersection of the i-th row and the j-th column.
(4)	$CI=\frac{\lambda max-n}{n-1}$
(5)	$CR=\frac{CI}{RI}$ In general, if CR is less than or equal to 0.1, the matrix is considered consistent. If CR is greater than 0.1, then you need to look at the pairwise comparison matrix estimates. development options

Thus, further calculations should be made (via a computer program, obviously). The purpose of the proposed program is to carry out simulation (computer) modeling in system analysis using the method of binary comparisons (Table 4).

Table 4. Matrices of pairwise comparisons

Characteristics	Matrices

Matrix of pairwise comparisons of circular economy factors at E(++)

	F1	F2	F3	F4	F5	F6	F7	F8
F1	1	1	2	1	4	1/3	1/2	4
F2	1	1	1	1	1	1/4	1/3	5
F3	1/2	1	1	1	1	1/6	2	7
F4	1	1	1	1	1	1/5	1/4	4
F5	1/4	1	1	2	1	1/7	1/6	8
F6	3	4	6	5	7	1	3	6
F7	2	3	1/2	4	6	1/3	1	5
F8	1/4	1/5	1/7	1/4	1/8	1/6	1/5	1

	u_{11}	u_{12}	u_{13}	u_{14}	u_{15}	u_{16}	u_{17}	u_{18}
S_j	0.11	0.08	0.09	0.07	0.06	0.36	0.12	0.02

Matrix of pairwise comparisons of circular economy factors at E(+)

	F1	F2	F3	F4	F5	F6	F7	F8
F1	1	2	3	7	4	5	8	9
F2	1/2	1	2	6	3	4	7	8
F3	1/3	1/2	1	5	1	3	6	7
F4	1/7	1/6	1/5	1	1	1	2	3
F5	1/4	1/3	1	1	1	2	5	6
F6	1/5	1/4	1/3	1	1/2	1	4	5
F7	1/8	1/7	1/6	1/2	1/5	1/4	1	4
F8	1/9	1/8	1/7	1/3	1/6	1/5	1/4	1

	u_{21}	u_{22}	u_{23}	u_{24}	u_{25}	u_{26}	u_{27}	u_{28}
S_j	0.33	0.23	0.15	0.05	0.10	0.06	0.03	0.01

Matrix of pairwise comparisons of circular economy factors at E(+/-)

	F1	F2	F3	F4	F5	F6	F7	F8
F1	1	2	4	3	5	7	6	8
F2	1/2	1	3	6	4	2	5	5
F3	1/4	1/3	1	4	2	2	3	3
F4	1/3	1/6	1/4	1	1/3	1/5	2	1
F5	1/5	1/4	1/2	3	1	1/3	2	2
F6	1/7	1/2	1/2	5	5	1	4	4
F7	1/6	1/5	1/3	1/2	1/2	1/4	1	1
F8	1/8	1/5	1/3	1	1	1/4	1	1

	u_{31}	u_{32}	u_{33}	u_{34}	u_{35}	u_{36}	u_{37}	u_{38}
S_j	0.34	0.23	0.12	0.04	0.06	0.11	0.03	0.03

Matrix of pairwise comparisons of circular economy factors at E(--)

	F1	F2	F3	F4	F5	F6	F7	F8
F1	1	1	2	1	3	1/2	1	3
F2	1	1	1	1	2	1/3	1/2	4
F3	1/2	1	1	2	1	1/5	1	6
F4	1	1	1/2	1	4	1/4	1/3	3
F5	1/3	1/2	1	1/4	1	1/6	1/5	7
F6	2	3	5	4	6	1	2	5
F7	1	2	1	3	5	1/2	1	4
F8	1/3	1/4	1/6	1/3	1/7	1/5	1/4	1

	u_{41}	u_{42}	u_{43}	u_{44}	u_{45}	u_{46}	u_{47}	u_{48}
S_j	0.13	0.10	0.10	0.09	0.05	0.31	0.16	0.02

Matrix of pairwise comparisons of circular economy factors at E(-)

	F1	F2	F3	F4	F5	F6	F7	F8
F1	1	1	1	4	1	2	5	6
F2	1	1	1	3	1	1	4	5
F3	1	1	1	2	1	1	3	4
F4	1/4	1/3	1/2	1	1	1	1	1
F5	1	1	1	1	1	1	2	5
F6	1/2	1	1	1	1	1	1	2
F7	1/5	1/4	1/3	1	1/2	1	1	1
F8	1/6	1/5	1/4	1	1/5	1/2	1	1

	u_{51}	u_{52}	u_{53}	u_{54}	u_{55}	u_{56}	u_{57}	u_{58}
S_j	0.22	0.18	0.16	0.07	0.14	0.10	0.06	0.04

To study a technological process, it is important to identify the totality of factors that characterize it and establish the weight of the influence of each of them. The advantage of one factor over another is assessed using expert assessments. Often, due to the presence of a large number of factors of different nature, it is

difficult for an expert to give a real assessment of each of them. Therefore, they compare two factors in pairs and prefer one or the other.

The calculations performed were carried out correctly, since the value of the largest eigenvalue, the consistency coefficient and the level of inconsistency for each of the matrices are within acceptable limits.

An important last step is to synthesize the priorities of the factors influencing the circular economy. To do this, the level of influence of a certain factor on the functioning and activity of such open socio-economic systems as enterprises (Ui) is established according to formula (6):

$$U_i = \sum_{i=1}^{n} wi * ui; j = 1, \dots\dots, m \tag{6}$$

where wi is the priority of the i-th level of changes in the influence of the circular economy factor on the development of Ukrainian enterprises (i = 1, ..., 5); uij is the relative weight of each element (j = 1.....8) according to the i-th level of changes in the influence of the factor (i = 1,..., 5). So in our case, it will look like this (7):

$$U_i = w1 * u1i + w2 * u2i + w3 * u3i + w4 * u4i + w5 * u5i \tag{7}$$

Thus, by substituting the corresponding values into the system of equations, we obtain the following priority values (Fig. 3).
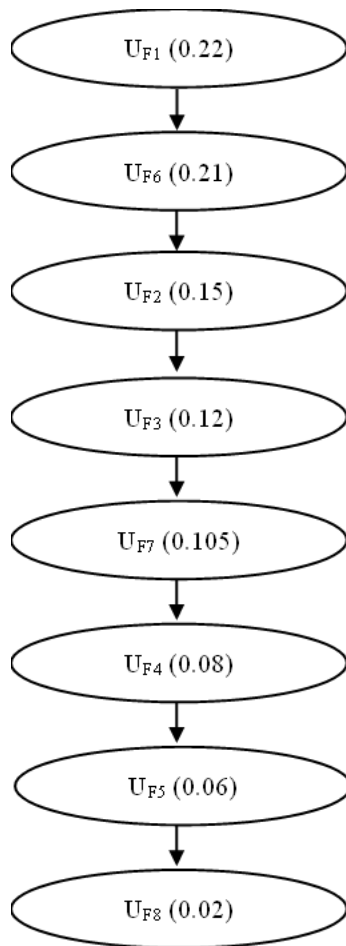

Figure 3 Hierarchy of priority of influence of circular economy factors

Thus, it is calculated that it is F1 and F2 among all the factors that have the most significant impact today.

Regulatory and policy inconsistencies (UF1) often represent the most significant barrier to the development of the circular economy. Effective policies act as the backbone of sustainable practices by setting standards, defining compliance mechanisms, and incentivizing positive behaviors. Inconsistencies or the absence of supportive policies can lead to uncertainty and discourage investment in circular practices. To address this, governments must prioritize the harmonization of laws and policies across different jurisdictions and sectors. Establishing clear, consistent regulations that support recycling, reuse, and waste reduction is crucial.

Economic and financial hurdles (UF6) are equally critical because they directly affect the feasibility and attractiveness of circular economy investments. The higher initial costs associated with transitioning to circular models, such as redesigning products for easier disassembly or establishing recycling facilities, can be prohibitive. To overcome these financial barriers, it is essential to create economic incentives that lower the risk and increase the profitability of such investments. This could include offering tax breaks, grants, or low-interest loans for businesses adopting circular practices.

Without delving into the complex current situation in all spheres of life in Ukraine, it can be stated that, along with other barriers that previously became an obstacle to the transition to a circular economy, today the dominant influence is exerted by military actions with their destructive impact on human resources, economic stability and environmental damage. At the same time, we must not lose sight of such an important point as post-war reconstruction, the financing of which is the subject of consideration by the most influential international institutions. Therefore, it is important that this recovery is carried out on the basis of the principles of a circular economy, which will bridge the pre-existing gap and make the national economy competitive.

DISCUSSIONS

Fadhil et al. (2022) employ AHP in sensory analysis of Pliek U, revealing the method's versatility in assessing subjective consumer preferences which are inherently qualitative in nature . Although their application primarily focuses on product analysis, it shares a commonality with our study in its effort to quantify qualitative data, thereby making it analytically tractable. This parallels our methodological approach where qualitative judgments about the impact of circular economy factors are systematically quantified to inform strategic decision-making. In a study by Rimadeni et al. (2024), AHP is integrated with spatial analysis to determine optimal locations for logistics distribution centers . The combination of geographical data analysis with hierarchical decision-making exemplifies the adaptability of AHP to interdisciplinary approaches, similar to how our study incorporates expert analysis and the Delphi method to enhance the robustness of the factor selection process in a socio-economic context.

Further, Tubishat et al. (2024) explore the efficiency of commercial relations in open systems through a regional legal lens, emphasizing the strategic planning aspects underpinned by AHP . Their focus on uninterrupted sustainable development aligns with our investigation into circular economy practices, underlining AHP's efficacy in strategic planning across diverse operational and regulatory environments. Domnikov et al. (2022) utilize AHP under conditions of uncertainty to develop energy systems . This study is particularly relevant as it showcases AHP's capability to handle multiple criteria in decision-making processes where uncertainty prevails, akin to our setting where enterprises must adapt to both economic and military disruptions. Nondek and Smutný (2012) integrate mathematical clustering with SWOT analysis, emphasizing the design of sustainable development strategies . Though not exclusively reliant on AHP, their methodological innovation provides a conceptual scaffold that complements the hierarchical analysis, particularly in synthesizing complex data sets into actionable strategies, resonating with our methodical arrangement for tactical measures in response to circular economy factors.

Lastly, Shakhatreh (2024) explores the impact of external environmental factors on sustainable commercial development, using AHP to assess legal aspects of eco-business in Jordan . This highlights AHP's application in evaluating external influences on business operations, similar to our study's focus on the impact of military operations on economic systems.

By reflecting on these diverse applications and methodological nuances of AHP as seen in recent scholarly work, it becomes evident that AHP not only offers a rigorous framework for decision-making in complex scenarios but also provides a flexible tool adaptable to various research needs and contexts. The findings from these studies collectively underscore the broad potential of AHP to contribute significantly to the theoretical and practical advancements in managing and strategizing within complex, open socio-economic systems.

Our research distinguishes itself by combining AHP with expert analysis and the Delphi method, a synergy not commonly found in the existing literature. This innovative approach leverages the strengths of AHP in structuring complex decision-making processes and complements it with the robustness of expert opinions refined through the Delphi method. This integration is particularly adept at capturing the nuances of circular economy factors that are influenced by both predictable market forces and unpredictable external pressures such as geopolitical disruptions (Table 5).

Table 5. The main innovations

Innovations	Characteristics
Focus on Circular Economy in Conflict-Affected Areas	Another innovative aspect of our study is its focus on the circular economy in an environment affected by military operations. The choice of Ukrainian enterprises operating under these challenging conditions provides unique insights into how businesses adapt circular economy practices in less-than-ideal circumstances. This focus is not only timely given the current global emphasis on sustainability and resilience but also relevant for policymakers and business leaders in similar socio-economic contexts globally
Development of a Conceptual Framework	The formulation of a conceptual approach that uses AHP to streamline and prioritize the influence of various factors on the circular economy represents a significant methodological innovation. This framework allows for the dynamic adaptation of business strategies to rapidly changing external conditions, facilitating a more agile response to disruptions. The strategic flexibility offered by this framework can serve as a model for other open socio-economic systems worldwide, seeking to integrate circular economy principles into their core operations
Contribution to Strategic and Tactical Planning	Our results provide a solid foundation for strategic and tactical planning by highlighting the most influential circular economy factors and the extent of their impact. The detailed analysis and prioritization help enterprises not only in responding effectively to immediate challenges but also in aligning their long-term objectives with sustainable practices. This proactive approach to planning is crucial for businesses aiming to maintain competitiveness and sustainability in an increasingly complex global market

The methodology and findings of our research have broader implications for the study of circular economies in open systems. By demonstrating how AHP can be adapted to address specific regional and sectoral challenges, this study enriches the discourse on sustainable development and provides a replicable model for other researchers and practitioners. The innovative use of AHP in this context enhances its applicability as a decision-making tool in both academic research and practical applications, particularly in scenarios requiring the balance of multiple, often conflicting, criteria.

CONCLUSION

Today, there is a synchronous increase in the risks of loss of biodiversity due to increased technogenic impact on the environment in the form of an increase in waste volumes, in particular harmful waste, with limitations or shortages of natural resources necessary to meet the needs of an increasing number of the planet's population, which generally determines the need for waste from a linear economy to the benefit of a circular one. Thus, the circular economy has a number of advantages, which are most realized through the ability to comply with the principles of sustainable development, as well as more efficient use of the resource base based on the design of each new product, taking into account the continuation of its life cycle and the possibility of recycling components and subsequent use. At the same time, as it was found, in addition to differences in the effectiveness of using individual tools of the circular economy, the main obstacle for less economically developed countries, which today includes Ukraine, is the need to implement significant transformational changes in the conditions of each enterprise based on the widespread introduction of innovations rational use of resources, processing and return of secondary raw materials to the production cycle. Such transformations are possible on the basis of high technologies implemented within the framework of the Fourth Industrial Revolution, when, in fact, resource orientation dominates in Ukraine with the results of military confrontation that are relevant today. Environmental, social and economic losses today cannot be determined, but only recorded due to the further unfolding of events.

Our findings confirm the efficacy of the AHP method in dissecting complex socio-economic challenges into manageable segments for better decision-making and strategy formulation. The method proved invaluable in prioritizing the circular economy factors according to their impact and relevance, thereby enabling targeted and effective interventions. The integration of expert opinions through the Delphi method further enriched the analysis, ensuring a well-rounded approach to the selection and prioritization of factors. A crucial outcome of this research is the development of a conceptual approach that leverages hierarchy analysis to streamline and enhance the flexibility of implementing circular economy principles. This approach not only facilitates the adaptation of strategies to meet the strategic goals of enterprises but also accommodates the dynamic nature of open socio-economic systems, particularly in contexts disrupted by military conflicts. Moreover, the study deepened the theoretical foundations of the circular economy, extending its applicability in scenarios marked by significant external disruptions. The comprehensive review and generalization of analytical materials helped in establishing a holistic vision of this economic model, emphasizing its potential to contribute effectively to sustainability and resilience in socio-economic systems.

The developed methodology and conceptual approach provide a robust framework for Ukrainian enterprises, and potentially others in similar contexts, to plan and implement measures that effectively respond to and harness the benefits of circular economy factors. This is particularly pertinent for ensuring economic sustainability and strategic agility in times of uncertainty.

The study is limited by not taking into account all possible factors of a circular economy. In addition, limitations relate to the fact that the group of experts involved is not so large. At the same time, future research should be devoted to the strategy of post-war reconstruction in which: hierarchical modernization of existing production capacities in terms of reducing the energy and material intensity of products, in particular based on maintaining the innovative activity of enterprises; development of a culture of rational consumption of the total social product and behavior with waste among the population; best waste management practices, in particular from Sweden, which today imports such resources to convert them into secondary raw materials; implementation of a reuse program through the repair and modernization of durable equipment, which is more profitable than recycling and the generation of secondary raw materials, but requires the creation and support of appropriate infrastructure.

REFERENCES

Barić, D., Pižeta, F. (2018). An AHP model for level crossing design. International Journal of Safety and Security Engineering, Vol. 8, No. 1, pp. 65-76. https://doi.org/10.2495/SAFE-V8-N1-65-76

Cerya, E., Idris, I., Marta, J. (2023). Enablers and barriers of implementing circular economy for Micro and Small Manufacturing Enterprises (M-MSEs) in West Sumatera. International Journal of Sustainable Development and Planning, Vol. 18, No. 11, pp. 3567-3573. https://doi.org/10.18280/ijsdp.181121

Domnikov, A., Khodorovsky, M., Domnikova, I. (2022). Methodological approach to choosing alternatives for the development of energy systems in conditions of uncertainty and multi-criteria. International Journal of Energy Production and Management, Vol. 7, No. 3, pp. 276-286. https://doi.org/10.2495/EQ-V7-N3-276-286

Donegan, H.A., Dodd, F.J., & McMaster, T.B. (1992). A new approach to AHP decision-making. The Statistician, 41, 295–302.

Fadhil, R., Agustina, R., Mustaqimah, Pradyta, S. (2022). Sensory analysis of Pliek u using the Analytical Hierarchy Process (AHP) method. International Journal of Design & Nature and Ecodynamics, Vol. 17, No. 4, pp. 601-606. https://doi.org/10.18280/ijdne.170415

Ghisellini, P., Cialani, C. & Ulgiati, S., (2016) A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems. Journal of Cleaner Production, 114, pp. 11–32. https://doi.org/10.1016/j.jclepro.2015.09.007

Kryshtanovych, M., Filippova, V. . ., Huba, M., Kartashova, O., & Molnar, O. (2020). Evaluation of the implementation of the circular economy in EU countries in the context of sustainable development. Business: Theory and Practice, 21(2), 704-712. https://doi.org/10.3846/btp.2020.12482

Makkulawu, A.R., Soemarno, Santoso, I., Mustaniroh, S.A. (2023). Exploring the potential and benefits of AHP and GIS integration for informed decision-making: A literature review. Ingénierie des Systèmes d'Information, Vol. 28, No. 6, pp. 1701-1708. https://doi.org/10.18280/isi.280629

Mu, E. (2006). A unified framework for site selection and business forecasting using ANP. Journal of Systems Science and Systems Engineering, 15(2), 178–188.

Muafi (2021). The influence of green culture and green strategy on the circular economy implementation: The moderating role of green intellectual capital. International Journal of Sustainable Development and Planning, Vol. 16, No. 6, pp. 1101-1108. https://doi.org/10.18280/ijsdp.160611

Nondek, L., Smutný, M. (2012). Mathematical clustering integrated with swot analysis as a tool for design of sustainable development strategies. International Journal of Sustainable Development and Planning, Vol. 7, No. 4, pp. 397-411. https://doi.org/10.2495/SDP-V7-N4-397-411

Rimadeni, Y., Sofyan, H., Rahman, S., Pramana, S., Juellyan. (2024). Determination of logistics distribution centers: A combination of spatial analysis and analytical hierarchy process. Journal Européen des Systèmes Automatisés, Vol. 57, No. 2, pp. 609-624. https://doi.org/10.18280/jesa.570229

Saaty, T.L., & Peniwati, K. (2007). Group decision-making: Drawing out and reconciling differences. Pittsburgh, PA: RWS Publications.

Saaty, T.L., & Shang, J.S. (2007). Group decision-making: Head-count versus intensity of preference. Socio-Economic Planning Sciences, 41, 22–37.

Shakhatreh, H.J.M. (2024). Impact of external environmental factors on sustainable commercial development in the Jordan: The case of legal aspect of the eco-business. International Journal of Environmental Impacts, Vol. 7, No. 1, pp. 93-100. https://doi.org/10.18280/ijei.070111

Hye, Q. M.A., (2011). Financial development index and economic growth: empirical evidence from India. The Journal of Risk Finance, 12(2), 98-111.

Shahbaz, M., Hye, Q. M. A., Tiwari, A. K., & Leitão, N. C. (2013). Economic growth, energy consumption, financial development, international trade and CO2 emissions in Indonesia. Renewable and sustainable energy reviews, 25, 109-121.

Shyra, T., Shtyrov, O., Korchynskyy, I., Zerkal, A., & Skoryk, H. (2020). Providing the corporate security strategy in the management system of the enterprise. Business: Theory and Practice, 21(2), 737-745. https://doi.org/10.3846/btp.2020.12975

Stankevičienė, J., & Nikanorova, M. (2020). Eco-innovation as a pillar for sustainable development of circular economy. Business: Theory and Practice, 21(2), 531-544. https://doi.org/10.3846/btp.2020.12963

Tubishat, B.M.A.R., Alazzam, F.A.F., Viunyk, O., Yatsun, V., Horpynchenko, O. (2024). Planning to improve the efficiency of open systems commercial relations to ensure uninterrupted sustainable development: Regional legal aspect. International Journal of Sustainable Development and Planning, Vol. 19, No. 3, pp. 1089-1097. https://doi.org/10.18280/ijsdp.190327

Vanhamaki, S., Medkova, K., Malamakis, A., Kontogianni, S., Marisova, E., Dellago, D.H., Moussiopoulos, N. (2019). Bio-based circular economy in European national and regional strategies. International Journal of Sustainable Development and Planning, Vol. 14, No. 1, pp. 31-43. https://doi.org/10.2495/SDP-V14-N1-31-43

Waheed, M., & Jam, F. A. (2010). Teacher's intention to accept online education: Extended TAM model. Interdisciplinary Journal of Contemporary Research in Business, 2(5), 330-344.

Yang, Z.H. (2020). Analysis of the impacts of open residential communities on road traffic based on AHP and fuzzy theory. Ingénierie des Systèmes d'Information, Vol. 25, No. 2, pp. 183-190. https://doi.org/10.18280/isi.250205