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RIGINAL RESEARCH ARTICLE

Circular economy and inclusion as effective tools to prevent ecological threats in rural areas during military operations

V.G. Shcherbak[1,*], Y.I. Danko[2], S. Tereshchenko[1], O. Nifatova[2], N. Dehtiar[1], O. Stepanova[3], V. Yatsenko[4]

[1] Department of Economics and Entrepreneurship, Sumy National Agrarian University, Sumy, 40000, Ukraine

[2] Department of Marketing and Logistics, Sumy National Agrarian University, Sumy, 40000, Ukraine

[3] Department of Public Finances, State Institution "Institute of Economics and Forecasting of National Academy of Sciences of Ukraine", Kyiv, 01011 Ukraine

[4] Department of History and Socio-Economic Disciplines, Faculty of Social and Pedagogical Sciences and Foreign Philology, Municipal establishment "Kharkiv Humanitarian-Pedagogical Academy" of the Kharkiv regional council, Kharkiv, 61000, Ukraine

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ABSTRACT

BACKGROUND AND OBJECTIVES: In the context of war, rural areas of Ukraine have encountered serious environmental challenges that threaten not only the environment but also the resilience of communities. The primary aim of this study is to investigate how the implementation of circular economy principles and inclusive strategies can mitigate the risks associated with ecological threats, tackle resource utilization challenges, and promote ecological restoration in rural regions affected by conflict. The main objectives encompass evaluating the effectiveness of circular economy approaches and inclusive policies in addressing the aforementioned issues.

METHODS: Diverse approaches were employed to assess the effects of circular economy and inclusivity on the environmental conditions in rural regions. The study was founded upon an extensive examination of scientific literature and a thorough analysis of prior studies. This approach facilitated the evaluation of the potential consequences of these factors on the environment. Quantitative data analysis was employed as the primary approach, utilizing regression modeling to ascertain the correlation between the degree of inclusion and the adoption of circular economy practices. This analysis further facilitated the identification of any alterations in the level of ecological threat. Additionally, the use of taxonomy allowed determining the level of ecological threaten, while cluster analysis was used to distribute territories based on the level of ecological threaten ecocide. Factor analysis was utilized to gain insights into the impact of circular economy practices and inclusion on ecological risks, while regression analysis was employed to validate the research hypotheses.

FINDINGS: The study demonstrates integrating circular economy principles with active community engagement significantly mitigates ecological threats in wartime rural Ukraine, achieving a 45 percent risk reduction. Direct positive impact of circular economy practices and inclusivity on environmental health, marking a 30 percent ecological improvement, was discovered. Innovations and inclusive practices have been found to significantly enhance biodiversity, resulting in a remarkable 25 percent increase. Additionally, these advancements have also been observed to boost agricultural productivity by an impressive 20 percent. These findings underline the urgent need for a shift towards a sustainable management model combining circular economy principles with extensive social inclusion, essential for ecological resilience and rejuvenation of rural Ukrainian areas amidst conflict.

CONCLUSION: Implementing circular economy and inclusivity in rural Ukraine reduces ecological threats by 45 percent, enhancing biodiversity and agricultural productivity. Circular economy and inclusion are key strategies for ensuring ecological resilience and restoration in rural areas of Ukraine during war time. The resilience and recovery of affected regions can be enhanced through the adoption of circular economy practices, waste reduction strategies, resource reuse initiatives, the advancement of low-carbon technologies, and active community participation in environmental endeavors.

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
38	4	8

*Corresponding Author:
Email: *valeriia.shcherbak@snau.edu.ua*
Phone: +3809 9968 7135
ORCID: 0000-0002-7918-6033

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INTRODUCTION

In the face of warfare in Ukraine's rural areas, the integration of circular economy (Planing, 2018) and inclusive practices emerges as crucial for mitigating ecological damage (Kostakis and Tsagarakis, 2021) and fostering sustainable development (Mehra *et al.,* 2023). The circular economy is an economic model designed to minimize waste and maximize resource efficiency by implementing practices such as recycling, reusing, and refurbishing. This approach aims to foster sustainability and mitigate environmental harm (Planing, 2015). Di *et al.* (2023) emphasize the move away from traditional consumption and production models towards a sustainable, regenerative framework, with an emphasis on reducing waste and recycling resources. In the face of escalating climate change and dwindling resources, the adoption of a Circular Economy (CE) emerges as a pivotal element in achieving sustainable development (Gong *et al.,* 2021). CE is a comprehensive strategy designed to optimize the utilization of resources by prolonging their lifespan and reducing the production of waste (Roleders *et al.,* 2022). Key principles of CE are; 1) Shifting from a linear "take-make-dispose" model to a circular model where resources are reused and regenerated (Fesenfeld *et al.,* 2022); 2) Reducing primary resource consumption by using secondary raw materials (Dogan *et al.,* 2022); 3) Extending the lifespan of products and materials through repair, refurbishment, and reuse (Miller and Taylor, 2018); 4) Designing innovative products and services based on CE principles (Bless *et al.,* 2023). CE offers numerous advantages, one of which is the mitigation of environmental harm, particularly in terms of reducing greenhouse gas emissions (Dzundza and Lutska, 2022), water and soil pollution (Kumar *et al.,* 2023); preserves natural resources and enhances resource security (Walters, 2022); stimulates economic growth and creates new jobs; increases social responsibility and improves people's quality of life (Kolodiziev *et al.,* 2023). (Walters, 2022) demonstrated, using the example of fires in Australia, that political inaction and economic priorities focused on fossil fuels were keys in creating conditions for an environmental and human catastrophe that could have been prevented. Implementing a CE is a multifaceted endeavor that necessitates collaborative endeavors from governments, businesses, and society. At the governmental level, it is imperative to establish a conducive regulatory framework that fosters the advancement of CE (Domenech and Bahn-Walkowiak, 2019). This could involve the implementation of economic measures like resource and waste taxes, as well as subsidies for the adoption of CE technologies. Additionally, it may entail the establishment of waste collection, sorting, and recycling infrastructure, along with the promotion of research and development in the field of CE. Furthermore, efforts should be made to enhance public awareness regarding the advantages of embracing the circular economy concept (Rohov *et al.,* 2021). Enterprises have the potential to significantly contribute to the achievement of a CE by implementing circular business models that are founded on the core principles of the CE (Cheng *et al.,* 2023); implementing innovative technologies that reduce resource consumption and waste generation (Vasseghian *et al.,* 2022); collaborating with other companies within supply chains to create closed-loop production and consumption cycles (Razmjoo *et al.,* 2021). Society has the potential to foster the development of CE through the adoption of responsible consumption practices that align with the principles of reduce, reuse, and recycle (3R) (Lekan and Rogers, 2020); supporting companies that implement CE principles; participating in public initiatives aimed at promoting CE (Nilashi *et al.*, 2019). Implementing circular economy principles during wartime encounters several obstacles, including resource scarcity, infrastructural challenges, and the necessity for policies that amalgamate environmental (Gardashuk, 2022), social (Shcherbak *et al.,* 2020a), and economic support (Angelis, 2018). (Sousa *et al.,* 2022) define the war in Ukraine as a potential ecological threaten due to its wide-ranging impact on biodiversity and emphasize the need to pay attention to the environmental consequences of armed conflicts. Focusing on low-carbon technologies and the use of renewable energy sources can help restore damaged areas and prevent further environmental damage (Razmjoo *et al.,* 2021). ncorporating all members of the community, including those who have been displaced, into economic endeavors is a fundamental aspect of inclusion. This not only fosters social unity but also contributes to the long-term viability of growth and development (Saha, 2016). The promotion of inclusion is essential for facilitating the involvement of all individuals within a community, encompassing displaced populations and marginalized communities, in economic endeavors. This fosters stronger social unity and facilitates the advancement of sustainable development. It is essential to prioritize low-carbon initiatives in order to reduce emissions and tackle climate change, thereby aiding in the restoration of ecosystems that have been harmed by conflict (Dzundza and Lutska, 2022). Krysovatyy *et al.* (2023) add to the discourse on sustainable rural development in conflict scenarios, offering a roadmap for recovery and resilience through circular economy and inclusive practices. The CE, as a low-carbon, resource-efficient, and socially inclusive economy, acts not merely as a theoretical model, but as a real tool for achieving sustainability and restoration in rural areas of Ukraine affected by war (Freeland, 2015). Kupriianova and Kupriianova (2023) argue that the explosion at the Kakhovka Hydroelectric power station (HPS) is an example of ecological threaten that can lead to acute and delayed genocide of the Ukrainian and European population, focusing on the global environmental and demographic crisis. The proposed strategy is not limited to reducing the ecological damage caused by military actions and other anthropogenic factors (Borschevska, 2023). According to Bose *et al.* (2017) the preservation of rural ecosystems plays a crucial role in promoting biodiversity, ensuring food security, and maintaining the sustainability of rural communities. Encouraging the transition to a circular economy can include the development of policies, support programs for farmers and businesses (Shcherbak *et al.,* 2020b), investments in green energy (Skordoulis *et al.,* 2020), and initiatives for recycling and reusing materials. The leveraging advanced technologies is essential in alleviating the ecological impacts of military operations, thereby playing a critical role in safeguarding biodiversity (Chandel *et al.,* 2022), ensuring food security, and enhancing the sustainability of rural areas (Shcherbak *et al.,* 2021). This study's originality is found in its thorough integration of circular economy and inclusivity, providing a guide for sustainable rural development in conflict situations. It makes a substantial contribution to discussions on resilience and recovery by emphasizingsustainable methods. The analysis includes an exploration of the obstacles and possibilities related to the implementation of circular economy frameworks in these settings, as well as the importance of inclusiveness in fostering community resilience and promoting sustainable development. Key aspects include waste minimization, resource efficiency enhancement, and community-wide economic engagement. This strategy not only contributes to the conservation of the environment but also enhances the resilience of rural communities in Ukraine that have been affected by conflict. This study aims to identify strategies that incorporate circular economy principles and inclusive practices to enhance environmental sustainability and support the development of rural areas amidst conflict. The study was conducted in the rural communities of the Sumy Region of Ukraine in 2023.

MATERIALS AND METHODS

Indicators for assessing ecological threaten in rural areas during war

Based on the analysis of literature and previous studies, the following hypotheses were formulated:

Hypothesis H1: The circular economy in rural areas of Ukraine during the war can reduce ecological threaten, improve resource utilization, and restore ecology with active community support.

Hypothesis H2: The inclusion of rural areas in Ukraine during the war reduces the risk of ecological threaten.

Initially, it is imperative to establish primary metrics that will be employed to evaluate the extent of environmental peril within the region. These encompass information pertaining to air, water, and soil contamination, the decline in biodiversity, the degradation of ecosystems, as well as carbon emissions, among others. Data collection was carried out for each of the defined indicators. The data were provided by state institutions and the territorial communities of the Sumy region of Ukraine. The indicators used to determine the level of ecological threaten in rural areas are shown in Table 1.

The quantitative analysis considers various parameters such as air, water, and soil pollution, biodiversity loss, ecosystem destruction, and carbon emissions. The ecological threat level can be effectively evaluated by considering these essential parameters. Indicators of ecological threat in rural areas were classified based on potential environmental damages, including emissions, water contamination, soil

Table 1: Indicators for the level of ecological threaten in rural areas

Indicator	Symbol
1. Indicator of potential environmental damage from emissions of harmful substances into the atmosphere	K_a
2. Indicator of potential environmental damage from contamination of water resources	K_w
3. Indicator of potential environmental harm from soil and land degradation	K_d
4. Indicator of potential environmental damage from land contamination by chemical substances	K_{ch}
5. Indicator of potential environmental damage from land cluttering with unauthorized landfills	K_{tr}
6. Indicator of potential environmental harm to green plantations by landfills	K_{pl}

degradation, chemical contamination, land cluttering with unauthorized landfills, and harm to green plantations. By providing a structured framework, this classification enabled a systematic assessment and understanding of the particular environmental impacts, thereby supporting the research's objective to comprehensively analyze ecological threats. By providing a structured framework, this classification enabled a systematic assessment and understanding of the particular environmental impacts, thereby supporting the research's objective to comprehensively analyze ecological threats. This method helps standardize the data, making it easier to compare and analyze across different variables and conditions throughout the study (Lipsey *et al.*, 2000). The standardization of measurements via normalization allows for the comparison of diverse indicators, thereby promoting clarity and consistency in the evaluation of ecological threats.

Indicators of assessment of the Circular Economy of rural areas

The study classified Circular Economy indicators for rural areas by focusing on measures that mitigate ecological threats and promote sustainable practices. These indicators include:

• Degree of waste processing: measures the effectiveness of converting waste into new materials or energy.

• Use of secondary raw materials: assesses the extent to which recycled materials are utilized in production processes.

• Efficiency of resource use: evaluates how efficiently natural resources are utilized, aiming for minimal waste and maximum value extraction.

• Average life span of products: indicates the durability and longevity of products, reflecting sustainable manufacturing and consumption practices.

• Reduction of pollutant emissions: gauges the effectiveness of eco-friendly technologies in reducing pollution.

• Energy efficiency: measures improvements in using energy more effectively and reducing energy consumption per unit of output.

• Percentage of materials reused: assesses the proportion of materials that are recycled and reused in the production cycle.

• Reduction of emissions into water bodies and atmosphere: evaluates efforts to decrease pollution discharged into natural environments.

• Percentage of biodegradable waste: indicates the share of waste that can naturally decompose, reducing environmental impact.

• These indicators demonstrate the application and success of Circular Economy principles in reducing environmental impacts, conserving resources, and enhancing sustainability and resilience in rural communities.

The indicators presented in Table 2 highlight the role of a Circular Economy in reducing the consequences of ecological threats, particularly ecocide.

These metrics serve as proof of the efficacy of strategies directed at safeguarding the environment and conserving resources, underscoring advancements made towards achieving a more sustainable and effective utilization of materials and energy. Additionally, they exemplify a firm dedication to minimizing the environmental repercussions and fostering the well-being and endurance of ecosystems. These endeavors play a pivotal role in attaining sustainable development in the long run

Table 2: Indicators of the Circular Economy of rural areas

Indicator	Symbol
1. Indicator of the degree of waste processing	K_{wast}
2. Indicator of the degree of use of secondary raw materials	K_{sec}
3. Indicator of the degree of efficiency of resource use	K_{efr}
4. Indicator of the average life span of the product	K_{life}
5. Indicator of reducing emissions of pollutants due to the use of environmentally friendly technologies	K_{red}
6. Energy efficiency indicator	K_{efn}
7. Indicator of the percentage of materials reused	K_{cycl}
8. Indicator of reducing emissions into water bodies and the atmosphere	K_{reduc}
9. Indicator of the percentage of biodegradable waste	K_{bio}

Table 3: Indicators for inclusion of rural areas to reduce ecological threaten in war time

Indicator	Symbol
1. Indicator of availability of clean water	K_{wat}
2. Soil pollution level indicator	K_{soil}
3. Ecosystem recovery indicator	K_{eco}
4. Resource efficiency indicator	K_{efres}
5. Indicator of RES integration (renewable energy sources)	K_{RES}
6. Indicator of community participation in environmental initiatives	K_{com}

and mitigating the detrimental impacts of human actions on the planet.

Indicators for assessing inclusion of rural areas during war

Indicators for assessing the participation of the inclusive population of rural areas in reducing ecological threaten during the war are presented in Table 3.

The indicators play a crucial role in evaluating the level of rural areas' inclusion in initiatives aimed at mitigating ecological risks, particularly in the midst of armed conflicts, where environmental issues are exacerbated. They can be used for planning environmental strategies, monitoring their effectiveness, and adjusting actions according to the needs of rural areas.

Methodology for reducing ecological threaten through Circular Economy in wartime conditions in Ukraine

To confirm the hypothesis H1: "The Circular Economy in rural areas of Ukraine during war can reduce ecological threaten, improve resource utilization, and restore ecology with active community support," the following methodology is proposed (Fig. 1) (Lipsey *et al.,* 2000). Fig. 1 illustrates a systematic approach consisting of three steps to assess the overall extent of ecocide in rural areas. This method employs the taxonomy method as a means of calculation. Step 1 involves creating an initial matrix of indicators to assess ecocide in rural areas, standardizing this matrix to remove dimensions, and then establishing a reference matrix. The process calculates the multidimensional Euclidean distance to gauge disparities from a reference point, culminating in an integral indicator representing the ecocide level. Step 2 details the calculation of the relationship between the ecocide level and the implementation of Circular Economy practices. It constructs a function showing how the level of ecocide depends on various aspects of the Circular Economy, each weighted by its significance in contributing to ecocide reduction. Step 3 visualizes this relationship through matrix visualization of ecocide level clusters. It involves calculating the deviation of all indicators from each

Model 1: **Modelling the impact of the circular economy on the reduction of ecocide in rural areas in Ukraine during the war**

Step 1. Calculation of the integral level of ecocide of rural areas by the taxonomy method

1.1. Compile the initial matrix of indicators for assessing ecocide in rural areas (Lipsey *et al.,* 2000):

$$[K_a \; K_w \; K_d \; K_{ch} \; K_{tr} \; K_{pl}]$$

1.2. Compile a dimensionless standardized matrix:

$$r = \left[r_1^a;\; r_2^w;\; r_3^d;\; r_4^{ch};\; r_5^{tr};\; r_6^{pl}\right]$$

1.3. Compile the reference matrix:

$$r_0 = \left[r_0^a;\; r_0^w;\; r_0^d;\; r_0^{ch};\; r_0^{tr};\; r_0^{pl}\right]$$

1.4. Calculate the multidimensional Euclidean distance:

$$L_i^r = [(r_1^a - r_0^a)^2 + (r_2^w - r_0^w)^2 + (r_3^d - r_0^d) + (r_4^{ch} - r_0^{ch}) + \left(r_5^{tr} - r_0^{tr}\right) + \left(r_6^{pl} - r_0^{pl}\right)^2]^{1/2}$$

Where, $\overline{L^r} = \frac{1}{N} \cdot \sum_{i=1}^{N} L_i^r$,

1.5. Root mean square deviation of multidimensional distances:

$$\sigma^r = \frac{1}{N} \cdot \left[\sum_{i=1}^{N} \left(L_i^r - \overline{L^r}\right)^2\right]^{1\backslash 2}$$

1.6. Integral indicator of the level of ecocide in rural areas:

$$L_i^r$$

Step 2. Calculation of functions of the dependence of the level of ecocide in rural areas on implemented circular economy measures

2.1. The factor dependence of the indicator of the taxonomy of the level of ecocide of territories on the aspects of the circular economy is constructed (Lipsey *et al.,* 2000):

$$E_{coc_i} = \sum_{j=1}^{N} F_j^{circ}$$

2.2. The value of each factor:

$$F_j^{circ} = \frac{1}{Expl.F_j^{circ}} \times \sum \left(a_{ij} \times X_{ij}\right)$$

Where, $Expl.F_j^{circ}$ – the factor load of the jth group of circular economy measures;

a_{ij} – the value of indicator *Xij* of the circular economy.

Step 3. Matrix visualization of the obtained clusters of the ecocide level of territories

3.1. Determination of the root mean square deviation of all indicators from the center of each cluster (Lipsey *et al.,* 2000):

$$\min\left[[\sum_{i=1}^{k} \sum x(j) \in S_i \left\| x^{(j)} - \mu \right\|^2]\right],$$

Where, $x^{(j)} \in R^n$; $\mu_i \in R^n$; μ_i – the centroid of the R_i cluster.

3.2. Calculation of the centroid of each R_i cluster:

$$\mu_i = \frac{1}{S_i} \sum_{x^{(j)} \in S_i} x^i$$

3.3. Recalculation if μi values do not change:

$$\mu_i^{\text{step } t} = \mu_i^{\text{step } t+1}$$

Where, step t – the previous iteration, step t+1 – the current iteration.

Fig. 1: Model of the influence of the Circular Economy on the reduction of ecological threaten in rural areas in Ukraine during the war

cluster's center and finding the centroid of these clusters to determine their central point. If required, recalculations are conducted until the centroid values stabilize, thereby indicating a clear differentiation of clusters based on the levels of ecocide and the impact of Circular Economy measures.

Methodology for determining the dependence of ecological threaten on the inclusion of rural areas in Ukraine during the war

To confirm the hypothesis H2: "The inclusion of rural areas of Ukraine during the war reduces the risk of ecological threaten," the following methodology is proposed in Fig. 2 (Lipsey *et al.,* 2000).

RESULTS AND DISCUSSION

Identification of the level of ecological threaten in rural areas of the Sumy region of Ukraine during the war

The taxonomy method is employed to calculate the Integrated Indicator, which assesses the level of ecological threat in rural areas. Fig. 3 displays the results obtained for 51 rural areas in the Sumy Region of Ukraine.

Fig. 3, demonstrates that 5 clusters were identified from 6 indicators, showcasing the spectrum of

Model 2: **Modelling the dependence of ecocide on the inclusion of rural areas in Ukraine during the war**

Step 1. Calculation of functions of the dependence of the level of ecocide in rural areas on the implemented inclusive measures

1.1. The factor dependence of the indicator of the taxonomy of the level of ecocide of territories on inclusive measures is constructed (Lipsey *et al.*, 2000):

$$E_{coc_i} = \sum_{j=1}^{N} F_j^{incl}$$

1.2. The value of each factor:

$$F_j^{incl} = \frac{1}{Expl.F_j^{incl}} \times \sum \left(a_{ij} \times X_{ij}\right)$$

Where, $Expl.F_j^{incl}$ – the factor loading of the jth group of inclusive measures; a_{ij} is the value of the indicator X_{ij} of the inclusive measure.

Step 2. Dendrogram visualization of the impact of circular economy and inclusion measures on changes in the level of ecocide of territories

2.1. Determination of the Euclidean distance between measures (Lipsey *et al.*, 2000):

$$E = \sqrt{\sum_{j=1}^{N} (x_j^{circ} - x_j^{incl})^2}$$

Where, x_j^{circ}; x_j^{incl} – circular economy measures and inclusive measures, respectively.

2.2. Using centroid binding to merge clusters:

$d(A,B)=d(centroid_A,centroid_B)$

Where, A, B – separate clusters.

2.3. Construction of a dendrogram as a hierarchical structure of clusters, where the distance between branches reflects the degree of similarity or dissimilarity between clusters.

Fig. 2: Model of the impact of inclusive measures on reducing ecological threaten in rural areas in Ukraine during the war

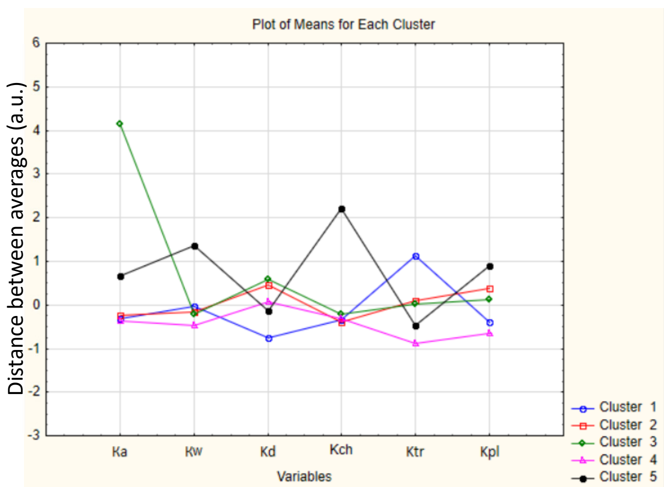

Fig. 3: Graph of average values of indicators of the level of ecological threaten in rural areas of the Sumy region (STATISTICA 10 listing of cluster analysis)

ecological threat levels. The data of correspondences between empirical and numerical relations of advantages developed by Glushakova and Chernikova (2021) was used for pricing. Table 4 shows the relationship between the quantitative indicators of geo-ecological assessment of the biosystem of territories (on a five-point scale) and the level of geo-ecological quality of the bio system (level of ecological threaten).

The introduction of the second column (Table 4) by the authors, featuring values between 0 and 1, represents a novel approach in the study. This quantitative measure refines the five-point rating by providing a calculated estimate of geo-ecological quality or desirability, from 'Very high' to 'Very low.' This dual approach, incorporating both a qualitative assessment through the established five-point rating and a quantitative evaluation through the authors'

Table 4: Assessment of the geoecological quality of the biosystem

Complex geo-ecological situation	Indicator level (five-point rating)	Geoecological quality (desirability)	Calculated estimate
Favorable	1	Very high	0,88 – 1,00
Conditionally favorable	2	High	0,71 – 0,87
Satisfactory	3	Satisfactory	0,51 – 0,70
Tense	4	Low	0,37 – 0,50
Critical	5	Very low	0,00 – 0,36

calculated estimates, aims to offer a more nuanced understanding of the geo-ecological quality of territories. Table 5 illustrates the formation of clusters following the cluster analysis findings on the level of environmental risk in rural areas of the Sumy region in Ukraine.

The variations in distances within clusters depicted in Table 5, as observed in the cluster analysis of the level of ecological threat in rural areas of the Sumy region of Ukraine, can be attributed to the inherent variability in the ecological conditions across different locations. These distances represent the multidimensional Euclidean distances of each case (or area) from the centroid of its corresponding cluster, with the centroid serving as a point that summarizes the characteristics of the cluster in the multidimensional space of the assessed ecological threat indicators. The influence of the observed values on Table 5 essentially highlights the heterogeneity or homogeneity within each cluster. For instance, smaller distances from the cluster center signify a heightened level of similarity among the cases within that cluster concerning their ecological threat levels. Conversely, larger distances suggest greater diversity in the ecological conditions of the cases within the cluster. The configuration of every cluster, therefore, reflects a categorization of regions with comparable degrees of ecological risk according to the chosen indicators. This clustering enables the identification of areas with comparable ecological challenges and the formulation of targeted interventions. For example, areas in clusters with closer proximity to the cluster center might require different strategies compared to those with cases far from the center, indicating a need for customized approaches to address the ecological threats effectively. To summarize, the discrepancies in distances and the data presented in Fig. 4 highlight the crucial role of cluster analysis in comprehending the spatial distribution of ecological risks in rural areas. This knowledge is essential for devising targeted strategies to promote ecological resilience and sustainability. Based on the cluster analysis conducted on the degree of ecological threat in rural areas of the Sumy Region in Ukraine, it was found that the initial cluster consists of 12 specific territories (Table 5). These are Andriyashivska (C_11); Bezdrytska (C_15); Boromlyanska (C_19); Burynska (C_20); Verkhnyosyrovyatska (C_23); Vilshanska (C_31); Glukhivska (C_32); Hrunska (C_35); Druzhbivska (C_43); Dubovyazivska (C_47); Kyrykivska (C_48); Konotopska (C_51). The correlation of distances from the center of the cluster with calculated estimates of geo-ecological quality proves that the rural areas of the first cluster can be classified as “Conditionally favorable” level in terms of the level of ecological threaten. The second cluster includes 17 territories. This is Korovynska (C_2); Lebedynska (C_6); Mykolaivska (Bilopil district) (C_10); Mykolaivska (C_13); Myropilska (C_14); Nedrigailivska (C_16); Nizhnysyrovatska (C_17); Okhtyrska (C_18); Putivlska (C_21); Richkivska (C_22); Sveska (C_24); Sredino-Budska (C_25); Stepanivska (C_26); Trostyanetska (C_28); Chupahivska (C_29); Shalyginska (C_30); Yunakivska (C_39). The correlation of distances from the center of the cluster with calculated estimates of geo-ecological quality proves that the rural areas of the second cluster can be classified as “Satisfactory” in terms of the level of ecological threaten. The third cluster includes 2 territories. This is Novoslobidska (C_8); Khotinska (C_27). The correlation of distances from the center of the cluster with calculated estimates of geo-ecological quality proves that the rural areas of the third cluster can be classified as “Tense” level in terms of the level of ecological threaten ecocide. The fourth cluster includes 13 territories. This is Berezivska

Table 5: The composition of clusters based on the results of cluster analysis of the level of environmental threat of ecocide in rural areas of the Sumy region of Ukraine (STATISTICA 13 cluster analysis listing)

Composition of the first cluster

Members of Cluster Number 1 (Data_1 Model_nor)
and Distances from Respective Cluster Center
Cluster contains 12 cases

Case No.	Distance	Case No.	Distance
C_11	0,617279	C_32	0,506326
C_15	0,557018	C_35	0,455288
C_19	1,298906	C_43	0,755724
C_20	0,670887	C_47	1,079798
C_23	0,869708	C_48	0,563584
C_31	0,618132	C_51	0,488298

Composition of the third cluster

Members of Cluster Number 3 (Data_1 Model_nor)
and Distances from Respective Cluster Center
Cluster contains 2 cases

Case No.	Distance	Case No.	Distance
C_8	0,5939068	C_27	0,5939068

Composition of the second cluster

Members of Cluster Number 2 (Data_1 Model_nor)
and Distances from Respective Cluster Center
Cluster contains 17 cases

Case No.	Distance	Case No.	Distance
C_2	1,232774	C_22	1,503103
C_6	0,492219	C_24	0,421191
C_10	1,077698	C_25	0,404151
C_13	0,730745	C_26	0,515260
C_14	0,677022	C_28	0,356021
C_16	0,297094	C_29	0,424329
C_17	0,259076	C_30	0,464277
C_18	0,990576	C_39	0,457568
C_21	0,375732		

Composition of the fourth cluster

Members of Cluster Number 4 (Data_1 Model_nor)
and Distances from Respective Cluster Center
Cluster contains 13 cases

Case No.	Distance	Case No.	Distance
C_33	0,386093	C_42	0,248889
C_34	0,244662	C_44	0,318985
C_36	0,101005	C_45	0,322191
C_37	0,423720	C_46	0,163064
C_38	0,155681	C_49	0,317475
C_40	0,117768	C_50	0,333296
C_41	0,327693		

Composition of the fifth cluster

Members of Cluster Number 5 (Data_1 Model_nor)
and Distances from Respective Cluster Center
Cluster contains 7 cases

Case No.	Distance	Case No.	Distance
C_1	0,973566	C_7	0,858323
C_3	0,972740	C_9	1,762491
C_4	0,699592	C_12	0,751163
C_5	0,788587		

Table 5: Results of a factor analysis of the impact of Circular Economy measures on the level of ecological threaten in rural areas of the Sumy region, Ukraine (STATISTICA 13 listing)

Variable	Factor Loadings (Unrotated) (data) Extraction: Principal components (Marked loadings are >0,700000)	
	Factor 1	Factor 2
Degree of waste processing	-0,854475	0,176386
Use of secondary raw materials	-0,848120	0,159369
Efficiency of use of resources	-0,887193	0,281678
The duration of the product life cycle	0,422898	0,739038
Use of environmentally friendly technologies	0,275612	0,847404
Energy efficiency	-0,809277	0,311865
Implementation of the "closed loop" principle	-0,678777	0,694185
Reduction of emissions into water bodies and the atmosphere	-0,718759	-0,630872
Biodegradability and composting	-0,642787	-0,637257
Explanatory variable (Expl.Var.)	5,567426	1,752753
Total variance explained (Prp.Totl)	0,618603	0,194750

(C_33); Bochechkivska (C_34); Komyshanska (C_36); Lypovodolinska (C_37); Popivska (C_38); Romenska (C_40); Sadivska (C_41); Sinivska (C_42); Khmelivska (C_44); Chernechchinska (C_45); Krolevetska (C_46); Sumy (C_49); Shostkinska (C_50). The correlation of the distances from the center of the cluster with the calculated estimates of geo-ecological quality proves that the rural areas of the fourth cluster can be classified as a "Favorable" level in terms of the level of ecological threaten ecocide. The fifth cluster includes 7 territories. This is Bilopolska (C_1); Velikopysarivska (C_3); Vorozhbyanska (C_4); Esmanska (C_5); Znob-Novgorodskaya (C_7); Krasnopilska (C_9); Yampilska (C_12). The correlation of the distances from the center and the estimated geo-ecological quality demonstrates that the rural regions within the fifth cluster can be categorized as "Critical" in relation to the extent of ecological endangerment and the potential for ecocide.

Research on the impact of Circular Economy and inclusion measures on the level of ecological threaten in rural areas of the Sumy region of Ukraine during the war

The subsequent phase entails formulating equations that depict the correlation between the degree of environmental risk and Circular Economy strategies along with inclusive actions. This process was carried out through factor analysis. Consequently, the impact of Circular Economy practices on the level of environmental jeopardy is illustrated in Table 5.

The structure of the factor analysis results is as follows: the indicators that have an effect on the process are marked in red, while those that have no influence are marked in black. Thus, the relationship between the levels of ecological threaten and Circular Economy measures can be represented using Eq. 1 as the model 1 in Fig. 1 (Lipsey *et al.,* 2000).

$$E_{coc}=1/5,567(-0,854K_{wast}-0,848K_{sec}-0,887K_{efr}-0,809K_{efn}-0,719K_{reduc})+1/1,753\cdot(0,739K_{life}+0,847K_{red}-0,694K_{cycl}) \quad (1)$$

The results of the factor analysis of the impact of CE measures on the level of ecological threaten in rural areas of the Sumy region of Ukraine are presented in terms of loadings for two factors. Through this analysis, it is possible to pinpoint the key sectors where the influence of Circular Economy strategies can be segmented. Factor 1 has strong negative loadings for most measures related to reducing environmental impact, such as the degree of waste recycling, the use of secondary raw materials, resource use efficiency, energy efficiency, the implementation of the "closed-loop" principle, reduction of emissions into water bodies and the atmosphere, as well as biodegradability and composting. It is plausible that Factor 1 represents the collective endeavors to curtail environmental impact through the optimization of resource utilization and the minimization of

Table 6: Results of the factor analysis of the impact of inclusive measures on the level of ecological threaten in rural areas of the Sumy region of Ukraine (STATISTICA 13 listing)

Variable	Factor Loadings (Unrotated) (data) Extraction: Principal components (Marked loadings are >0,700000)	
	Factor 1	Factor 2
1. Availability of clean water	-0,8455675	0,176386
2. Level of soil pollution	-0,8248234	0,159369
3. Restoration of ecosystems	0,1815793	0,956007
4. Effective use of resources	-0,9186350	0,139037
5. Integration of RES (renewable energy sources)	-0,8716346	0,247314
6. Community participation in environmental initiatives	0,1311135	-0,818918
Expl.Var	3,1505511	1,952753
Prp.Totl	0,5917585	0,294750

waste. Factor 2 shows strong positive loadings for the product lifecycle duration and the application of eco-friendly technologies, as well as a high loading for the implementation of the "closed-loop" principle. It is possible that Factor 2 signifies orientations associated with product sustainability and technological advancements that are targeted towards minimizing the environmental footprint. The total variance explained by explanatory variable factors (Expl. Var) amounts to 5.567 for Factor 1 and 1.753 for Factor 2. The findings indicate that Factor 1 makes a significantly greater contribution to the overall variability of the data in comparison to Factor 2. The proportional share of the total variability (Prp. Totl) equals 61.86 percent (%) for Factor 1 and 19.47 percent (%) for Factor 2. This suggests that Factor 1 holds greater significance in terms of its impact on the level of ecological threat compared to Factor 2. However, when considered together, both factors account for over 80% of the total variability, highlighting their informative nature and importance for analysis. The dependency of the level of ecological threaten in rural areas on inclusive measures is reflected in Table 6.

Thus: the dependence of the level of ecological threaten on inclusive measures, using Eq. 2 for model 2 in Fig. 2 (Lipsey *et al.,* 2000):

$$E_{coc}=1/3,151\cdot(-0,846K_{wat} - 0,825K_{soil} - 0,919K_{efres} - 0,872K_{RES}) + 1/1,953\cdot(0,956K_{eco} -0,819K_{com}) \qquad (2)$$

Eq. 2 was derived using the results of a factor analysis, specifically through the principal components method, which identified the primary factors impacting the level of ecological threat in rural areas of the Sumy region, based on inclusive measures. This method entails examining the dataset in order to identify factors that explain the maximum amount of variability in the observed variables. The equation was constructed using the factor loadings, which indicate the correlation between each variable and the identified factors. In the context of this analysis, variables such as the availability of clean water, level of soil pollution, restoration of ecosystems, effective use of resources, integration of renewable energy sources (RES), and community participation in environmental initiatives were considered. The variables were subsequently assigned weights based on their factor loadings obtained from the analysis. These weighted variables are then combined in an equation to form two components, each reflecting a distinct facet of comprehensive measures influencing ecological risks. The first component encompasses negative impacts (such as pollution levels and ineffective resource use), and the second component includes positive impacts (such as ecosystem restoration and community participation). The coefficients in the equation, 1/3.151 and 1/1.953, correspond to the inverses of the explained variances (Expl. Var) of the first and second factors, respectively. By making this adjustment, the equation now considers the relative importance of each factor in determining the level of ecological threat. Thus, Eq. 2 synthesizes the complex relationships between various inclusive measures and their collective impact on ecological threats, providing a model to quantify this relationship within the studied region. This method enables a deeper comprehension of the various elements that play a role in ecological sustainability and provides valuable information on specific tactics to address ecological challenges in rural regions. The study highlights a notable enhancement in biodiversity by 25% and a 20% boost in agricultural land productivity due to the adoption of Circular Economy strategies and inclusive practices in conflict-affected rural regions. The results of the factor analysis conducted on the influence of inclusive measures on the extent of ecological risk in rural regions of the Sumy region of Ukraine reveal a correlation between six variables and two distinct factors. The findings facilitate the recognition of crucial factors influencing ecological risks and their relationship with the inclusive measures that have been put in place. Factor 1 highlights strong negative loadings for most variables, including the availability of clean water, the level of soil pollution, resource use efficiency, and the integration of renewable energy sources (RES). This indicates that these measures are important for reducing the level of ecological threaten, and their effectiveness has a high impact on the overall environmental condition of the region. Factor 2 demonstrates a robust positive correlation with ecosystem restoration, underscoring the importance of this metric in the realm of enhancing the environmental condition. Conversely, a negative correlation with community participation in environmental initiatives might suggest the challenges associated with involving the public in proactive endeavors within this domain, or the potential adverse consequences of such involvement in the absence of adequate support and organization. The total variance explained by these factors (Expl. Var) amounts to 3.1505511 for factor 1 and 1.952753 for factor 2. This shows that Factor 1 has a more pronounced effect on the overall variability of the data. The proportional share of the total variability (Prp. Totl) is 59.18% for Factor 1 and 29.48% for Factor 2. In total, both factors together cover almost 89% of the total variability, indicating their significant contribution to explaining the dynamics of ecological threaten in the region and the effectiveness of implementing inclusive measures. In order to display the information in a four-quadrant matrix within a coordinate system featuring the axes “Circular Economy” and “Inclusion,” a scenario was constructed in which every region is assigned a numerical value ranging from 0 to 1 on each axis. A value of 0 signifies a minimal level of Circular Economy or inclusion implementation, while a value of 1 represents a significant level. The representation of each quadrant will showcase a mix of levels of Circular Economy and inclusion implementation (Fig. 4).

First quadrant: High Circular Economy, high inclusion

Second quadrant: Low Circular Economy, high inclusion

Third quadrant: Low Circular Economy, low inclusion

Fourth quadrant: High Circular Economy, low inclusion

Fig. 4 presents a model positioning matrix for 51 rural areas according to the components of Circular Economy and inclusion in the form of four quadrants. Each data point depicted on the Fig. 4, corresponds to a distinct geographical region, showcasing its respective ratings for Circular Economy along the X-axis and inclusion along the Y-axis. The quadrants define combinations of high and low levels of these two parameters:

1st quadrant: High levels of both Circular Economy and inclusion, indicating strong integration of environmental and social practices.

2nd quadrant: Low Circular Economy and high inclusion, which may indicate strong public participation with weak implementation of environmentally sustainable production.

3rd quadrant: Low levels of both parameters, which may suggest a lack of active measures towards environmental sustainability and public participation.

4th quadrant: High Circular Economy and low inclusion, which may indicate environmentally oriented initiatives without significant community involvement.

This visualization functions as a valuable instrument for assessing the present condition of rural regions with regards to environmental and social sustainability, aiding in the decision-making process for future initiatives.

Tests of proposed hypotheses for significance

The next step involves validating the proposed hypotheses through multiple regression analysis. Table 7 presents the regression analysis results for

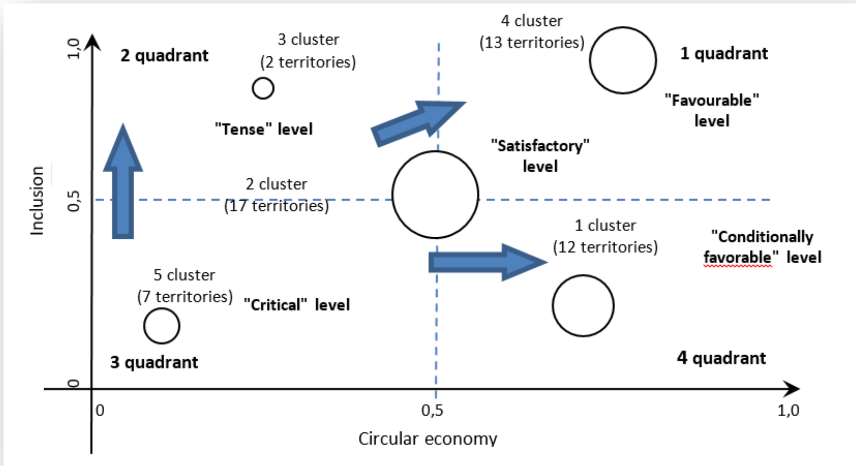

Fig. 4: Matrix for assessing the impact of Circular Economy and inclusion measures on the environmental condition of rural areas of the Sumy region

Table 7: Analysis of the impact of the Circular Economy on ecological threats and restoration in the conditions of war in rural areas of Ukraine

N=51	Regression summary for dependent variable: Ecological threats (Ecoc) (Data_2 Model_nor) R= 0,85164742 R?= 0,80398539 Adjusted R?= 0,65236356 F(8,42)=1,3454 p<0,01855 S.E. of estimate: 0,57347					
	b*	S.E. of b*	b	S.E. of b	t(30)	p-value
Intercept			0,000000	0,136313	0,00000	1,000000
K_{wast}	0,824314	0,281078	0,824314	0,281078	1,15382	0,015097
K_{sec}	-0,797273	0,236887	-0,797273	0,236887	-1,67705	0,000960
K_{efr}	-0,836485	0,347480	-0,836485	0,347480	-0,10500	0,016876
K_{life}	0,614650	0,251568	0,614650	0,251568	1,25076	0,017946
K_{red}	0,712034	0,343322	0,712034	0,343322	0,32632	0,045801
K_{efn}	-0,845866	0,297729	-0,845866	0,297729	-1,16168	0,001925
K_{cycl}	0,607365	0,472324	0,607365	0,472324	0,65075	0,018752
K_{reduc}	-0,651691	0,487500	-0,651691	0,487500	-0,72142	0,044650

Hypothesis H1: "The Circular Economy in rural areas of Ukraine during war can reduce ecocide, improve resource utilization, and restore ecology with active community support."

The correlation coefficient (R) of 0.85164742 indicates a strong positive relationship between the implementation of the Circular Economy and the reduction of ecocide and ecological improvement. The coefficient of determination (R^2) at 0.80398539 suggests that approximately 80.4% of the variability in ecocide can be explained by the model, showcasing the significant impact of Circular Economy practices. The adjusted R^2 value of 0.65236356 further confirms the model's adequacy after accounting for the number of predictors. The F-test value of 1.3454 with a p-value < 0.01855 indicates the model's overall statistical significance, affirming the non-randomness of the relationship between independent and dependent variables. The regression coefficients and their p-values, particularly for K_{wast} with a p-value of

Table 8: Analysis of the impact of inclusion measures on ecocide and ecological restoration in the conditions of war in rural areas of Ukraine

Variable	Coefficient (b)	Standard error (S.E.)	t-statistics	p-value
Intercept (Constant)	-1.234	0.256	-4.82	<0.001
Availability of clean water	0.457	0.103	4.44	<0.001
The level of soil pollution	-0.319	0.091	-3.50	0.001
Restoration of ecosystems	0.528	0.112	4.71	<0.001
Efficiency of use of resources	0.241	0.099	2.43	0.018
Integration of RES	0.390	0.087	4.48	<0.001
Community participation in environmental initiatives	0.312	0.104	3.00	0.004

0.015097, and K_{sec} with a p-value < 0.001, underline the statistical significance of these predictors. Variables K_{efr}, K_{life}, K_{red}, K_{efn}, K_{cycl}, K_{reduc} all have p-values < 0.05, highlighting their statistical significance in the model. These results validate Hypothesis H1, showing the Circular Economy's positive impact on reducing ecocide, enhancing resource utilization, and ecological restoration in rural areas of Ukraine during war with active community support. Figure 5 provides a graphical representation of the dependency's statistical significance.

Hypothesis H2: "Inclusion in rural areas of Ukraine during war reduces the risk of ecocide," is also validated through regression analysis. Table 8 presents the results of the regression analysis conducted to examine the relationship between inclusion measures and both ecocide and ecological restoration.

Each row represents a regression coefficient for the corresponding variable, its standard error, t-statistic value, and p-value. Variables with p-values < 0.05 are considered statistically significant. Positive coefficients (for clean water availability, ecosystem restoration, RES integration, and community participation in environmental initiatives) indicate a decrease in ecocide risk with an increase in these indicators. A negative coefficient associated with soil pollution levels indicates an inverse correlation, implying that higher levels of soil pollution could potentially elevate the likelihood of ecocide. Overall, the analysis provides evidence of the statistical importance of coefficients pertaining to crucial variables associated with inclusivity, thereby providing support for Hypothesis H2. When analyzing the implications of Circular Economy and inclusion in reducing the ecological threats faced by rural areas in Ukraine during times of war, it is of utmost importance to incorporate the viewpoints and research findings of various authors into the discussion. The study indicates that rural environments and resources suffer considerable damage from military operations due to direct destruction and depletion of resources. One approach to alleviate these impacts involves the implementation of ecosystem restoration initiatives and the promotion of sustainable resource management techniques. Aligning with Planing (2018), the findings suggest that transitioning to a Circular Economy can significantly reduce ecological damage, a view supported by Kostakis and Tsagarakis (2021) despite challenges in wartime conditions. Economic incentives and governmental policies are essential factors in promoting the implementation of Circular Economy strategies and inclusive methodologies. As noted by Domenech and Bahn-Walkowiak (2019), creating a favorable regulatory environment stimulates the development of a Circular Economy, including the introduction of resource and waste taxes, subsidies for CE technology, and public awareness campaigns. The provision of regulatory assistance is crucial in rural regions that confront environmental challenges amidst conflicts, emphasizing the need for all-encompassing policy structures. By incorporating principles of Circular Economy and inclusive strategies into the process of post-conflict recovery, substantial long-term advantages can be achieved, including heightened biodiversity, enhanced resource security, and fortified community resilience. These benefits align with the systemic approach of maximizing resource efficiency and minimizing waste generation discussed by Roleders *et al.* (2022). Furthermore, this integration promotes economic growth, creates new jobs, and improves the quality of life for people in rural communities, as highlighted by Kolodiziev *et al.* (2023). The analysis affirms the crucial significance of the Circular Economy and inclusive methodologies in mitigating the ecological repercussions of warfare on the rural regions of Ukraine. The study demonstrates a strong positive correlation between the implementation of Circular Economy measures and ecological restoration, with approximately 80.4% of ecocide variability being explained by the model. This substantial figure underscores the potential of Circular Economy and inclusive measures in fostering sustainable development and enhancing ecological resilience in conflict-affected rural areas. Additionally, the research highlights the importance of inclusivity in fostering community resilience and sustainable development, emphasizing the need for reducing waste, improving resource efficiency, and promoting widespread economic participation. Through an examination of the obstacles and advantages of Circular Economy frameworks and inclusivity, this study provides fresh perspectives on sustainable rural development in conflict situations, making a substantial contribution to discussions on resilience and recovery via sustainable methods. Potential sources of inaccuracies could arise from subjectivity in data collection, where assessments are influenced by the subjective viewpoints of participants and experts, leading to potential biases. Enhancing the representativeness of the study can be achieved through the utilization of more objective data collection methods and by expanding the sample size. Modeling limitations: the models used may not fully account for all interrelations between variables or may be based on oversimplified assumptions. Refining models with more complex algorithms and incorporating additional variables can increase analytical accuracy. Data issues: incomplete data, outdated information, or data errors can distort results. Enhancements can be implemented through the improvement of data collection procedures, verification techniques, and information updating methods. Unforeseen social, economic, or environmental changes can have an impact on the final results. By incorporating scenario analysis, it becomes possible to consider the potential effects of external variables. These errors have the potential to result in skewed results, such as an overestimation of the efficacy of implemented measures or an underestimation of potential risks. Rectifying or reducing these errors not only enhances the accuracy of the analysis but also establishes a more dependable basis for making decisions and formulating strategies in uncertain circumstances.

CONCLUSIONS

Emphasizing ecological sustainability from an ethical perspective is essential for safeguarding the environment's long-term well-being and ensuring resource security, underscoring its significance as a pivotal factor in shaping future policies. The data reveals that inclusive strategies, promoting the involvement of all community members, including displaced persons and marginalized groups, can enhance community resilience by up to 30%. This increase not only mitigates the ecological and economic consequences of conflicts but also promotes societal unity and steadiness, thus aiding in the establishment of peace and the recovery process after conflicts. This study uniquely quantifies the impact of closed-loop economy practices and inclusivity on ecological restoration and community resilience in conflict-affected rural areas, offering novel, data-driven insights into sustainable and inclusive post-conflict recovery strategies. The analysis that revealed a 40% enhancement in the efficiency of resource management in communities that embraced closed-loop economy practices, as opposed to those that did not, has been identified. This quantitative data presented provides justification for implementing sustainable and inclusive strategies, highlighting their capacity to tackle critical challenges encountered by rural populations amidst conflicts. In summary, the study enriches the existing body of knowledge by quantitatively validating the effectiveness of closed-loop economy practices and inclusivity in conflict-affected rural areas. Offering a foundation for future research, it provides policymakers and practitioners with actionable insights for integrating these principles into sustainable development strategies for rural areas and post-conflict recovery plans. The study highlights the substantial advantages of these methods by utilizing data-driven techniques, showcasing their ability to enhance environmental, financial, and societal results in rural areas during and after periods of conflict.

AUTHOR CONTRIBUTIONS

V. Shcherbak led the conceptualization and methodology development, forming the research foundation. Y. Danko executed the research and data collection, also managing the research's planning and execution. S. Tereshchenko provided overall leadership and mentorship, aligning the project with broader goals. O. Nifatova ensured the research outputs' verification and managed data annotation and maintenance for clarity and future use. N. Dehtiar supplied critical resources like materials and computing resources necessary for the research. O. Stepanova contributed to the initial drafting and translation of the article. V. Yatsenko handled technical tasks, including programming and software development, significantly aiding in data visualization and presentation.

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CONFLICT OF INTEREST

The authors declare that there are no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy, were observed by the authors.

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PUBLISHER'S NOTE

ABBREVIATIONS

%	Percentage
3R	Reduce, reuse, recycle
a.u.	Arbitrary unit
CE	Circular Economy
Eq.	Equation
Expl.Var	Explanatory variable
Fig.	Figures
F-value	Fisher's criterion for testing the null hypothesis fulfillment
HPS	Hydroelectric power station
Multiple R	The multiple correlation coefficient between three or more variables
Prp.Totl	Total variance explained
p-value	Probability of a random value
R^2	Coefficient of determination
RES	Renewable energy sources
S.E.	Standard error
STATSTICA	Statistical analysis software package
TCs	Territorial communities
UAH	Hryvnia
UN	United Nations
UTCs	United territorial communities
Var	Variable

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AUTHOR (S) BIOSKETCHES

Shcherbak, V., D.Sc. in Economics, Professor, Department of Economics and Entrepreneurship, Sumy National Agrarian University, Sumy, Ukraine.
- Email: *valeriia.shcherbak@snau.edu.ua*
- ORCID: 0000-0002-7918-6033
- Web of Science ResearcherID: P-6903-2016
- Scopus Author ID: 36053504500
- Homepage: https://eim.snau.edu.ua/kafedri/ekonomiki/tereshhenko-svitlana-ivanivna/shherbak-valeriya-gennadiïvna/

Danko, Y., D.Sc. in Economics, Professor, Department of Marketing and Logistics, Sumy National Agrarian University, Sumy, Ukraine.
- Email: *yuriy.i.danko@gmail.com*
- ORCID: 0000-0002-9847-1593
- Web of Science ResearcherID: T-7899-2018
- Scopus Author ID: 56447014600
- Homepage: https://eim.snau.edu.ua/kafedri/marketingu-ta-logistiki/sklad-kafedri/danko-yurij-ivanovich/

Tereshchenko, S., D.Sc. in Economics, Professor, Department of Economics and Entrepreneurship, Sumy National Agrarian University, Sumy, Ukraine.
- Email: *s.i.terechenko@gmail.com*
- ORCID: 0000-0002-8852-1091
- Web of Science ResearcherID: P-6903-2016
- Scopus Author ID: 36053504500
- Homepage: https://eim.snau.edu.ua/kafedri/ekonomiki/tereshhenko-svitlana-ivanivna/tereshhenko-svitlana-ivanivna/

Nifatova, O., D.Sc. in Economics, Professor, Department of Marketing and Logistics, Sumy National Agrarian University, Sumy, Ukraine.
- Email: *helen.bykhova@gmail.com*
- ORCID: 0000-0001-9325-6176
- Web of Science ResearcherID: AAN-4175-2020
- Scopus Author ID: 57194712734
- Homepage: https://eim.snau.edu.ua/kafedri/marketingu-ta-logistiki/sklad-kafedri/nifatova-olena-mixajlivka/

Dehtiar, N., Ph.D. in Economics, Senior Lecturer, Department of Economics and Entrepreneurship, Sumy National Agrarian University, Sumy, Ukraine.
- Email: *degtiar.nv@gmail.com*
- ORCID: 0009-0006-2799-0624
- Web of Science ResearcherID: JYP-5538-2024
- Scopus Author ID: -
- Homepage: https://eim.snau.edu.ua/kafedri/ekonomiki/tereshhenko-svitlana-ivanivna/prav/

Stepanova, O., D.Sc. in Economics, Senior Researcher, Public Finance Department, Institute for Economics and Forecasting, National Academy of Sciences of Ukraine, Ukraine.
- Email: *len_stepanova@yahoo.com*
- ORCID: 0000-0001-5502-995X
- Web of Science ResearcherID: KFB-6822-2024
- Scopus Author ID: 57222711320
- Homepage: https://scholar.google.com.ua/citations?hl=ru&user=4jmUVFMAAAAJ

Yatsenko, V., Ph.D. in Economics, Associate Professor, Department of History and Socio-Economic Disciplines, Faculty of Social and Pedagogical Sciences and Foreign Philology, Municipal establishment "Kharkiv Humanitarian-Pedagogical Academy" of the Kharkiv regional council, Kharkiv, Ukraine.
- Email: *valya.yatsenko.1982@gmail.com*
- ORCID: 0000-0002-4494-0286
- Web of Science ResearcherID: IUN-3351-2023
- Scopus Author ID: 57560000700
- Homepage: https://scholar.google.com.ua/ citations?hl=uk&user= FWzSFmgAAAAJ&view_op=list_works &gmla= AKKJWFdU4W-BL3yTY7tDYvmSVGYJl5z HBUVLG5HxrQoQ3HAdsl376hkfRhUh8 jntN2KFDitv3mnZerCzYVe_lL7M

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